ENERGY USES AND SUPPLIES, 1939, 1947, 1965

BY HAROLD J. BARNETT

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FOREWORD

In January 1948, the Secretary of the Interior directed that a study be made of energy resources and requirements that would provide a basis for continuing appraisal of the adequacy of the Department's programs in the energy field. That this instruction was timely has been demonstrated by the increasing interest being evidenced by Congress, industry, labor, and the public in the future of the energy segment of our national economy. Several studies of individual energy sectors have appeared. Various legislative proposals have been made in Congress for obtaining more information on this subject.

Substantial interest in energy projections is not, of course, a recent innovation. Energy availability and consumption are strategic factors in peacetime prosperity and growth and in our national defense as well. The past generation's literature of earnest public discussion and of legislative consideration of matters involving energy projections is very extensive.

This is an exploratory study produced in the Program Staff of the Office of the Secretary of the Interior in the first half of 1949 and revised recently to take account of certain of the preliminary energy data from the 1947 Census of Manufactures and critical comments. It is offered at this time solely as a technical contribution in economic research technique. As the Bureau of Mines has recently undertaken to revise this preliminary study, critical and other comments are invited.

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SUBJECT

This is a summary of preliminary results of an exploratory study of energy uses and supplies in the United States. Although preliminary projections for 1965 are presented, the study is offered at this time primarily as a description of concepts and statistical apparatus in order to receive critical comment and to assist other researchers in this field.

As used in this paper, energy is defined as mineral fuels and developed water power. No animal energy, wood, solar energy, or atomic energy are included in these data.2/

NEED FOR GOVERNMENT AND INDUSTRY FORWARD PLANNING TO MEET ENERGY NEEDS

Several related circumstances in the energy economy necessitate forward planning to satisfy future energy needs. Energy resources are physically limited and, except for hydropower, undergo drain through time. Much time is needed to bring some of these natural resources into production, and even more time is needed to substitute on a large scale one source for another (for example, synthetic oil from coal for petroleum) or one energy commodity for another (for example, natural gas or fuel oil for coal in home furnace use). Very large-scale investment funds and facilities are needed whenever increased total demand or substitutions require expansion of energy-producing capacity. Much of the energy economy is not and cannot be perfectly competitive.

Energy supply is significant in individual and national economic welfare. It is generally believed, for example, that an adequate rate of growth in supplies of low-cost energy is a condition necessary to high

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2/ Relative to present energy supply from mineral fuels and water power, Eugene Ayres has estimated wood-fuel use at a level equivalent to about 5 percent. J. Frederick Dewhurst and Wilbert G. Fritz have estimated this use at about 4 percent and have estimated animal energy at about 1/10 of 1 percent. To the best of our knowledge, changes through time in the economy's reliance on the excluded energies do not perceptibly affect the major energy trends of the last 20 or 30 years and do not perceptibly affect our projections for 1965.

levels of productivity and advancing output per man-hour; that thwarting the energy demands of a growing economy would impede economic advance. Further, as the art of diplomacy does not preclude war, and as war uses much energy in direct military operations as well as in the domestic economy supporting such operations, energy sufficiency is important to national security.

These circumstances in combination require that government and the energy industries endeavor to anticipate and provide for satisfying future energy needs on the most efficient basis possible. To this end, numerous private and several government agency projections of requirements and supplies have appeared in recent years.

ROLE OF PROJECTIONS

A projection is not itself a plan. It is a statistical description of what is likely to happen under a specific set of circumstances. As such, it is data for policy officials in government and industry in planning to meet the future. A projection of electricity requirements, for example, merely tells the utility official what the future level of demand for kw.-hr. would be under specific circumstances. A projection is thus a tool, a particular kind of report, designed to assist policy and planning officials in their decision-making functions. It is never more than this.

But plans - not the forecaster's, but those of others, including the planning officials for whom the projections are made - do enter projections in the form of basic assumptions. A long-term projection of freight volume by railroad management, for example, takes account of production plans of coal-mine operators and the United Mine Workers. It also takes account of the reduction in coal freight volume that will result from railroad substitutions of Diesels for coal-burning locomotives. The fact is, then, that in some situations the forecaster necessarily makes assumptions about the future activities of the organization he serves, this despite the fact that such activities will, in part, ultimately rest upon the projections. But there is no real dilemma here - this only means that the end projection and the end plan will be reached by successive approximations.

In addition to serving policy makers in energy-producing and research operations, energy projections perform other useful functions. They provide other interested bodies, such as Congress, energy-consuming enterprises, investment officials, and the public in general with indications of probable developments in this important field. These bodies do not conduct direct energy-producing operations, but some are concerned with and do participate in the making of policy. Others are concerned with economic policies and operations in fields that depend on energy developments.

Another useful function of energy projections, albeit indirect, is to make a summary analysis of the future economic enviornment to which the energy sector will be related. Depending on the quality of this summary, this can be useful to government and private bodies concerned with the non-energy-producing sectors of the economy.

CHARACTERISTICS NEEDED IN ENERGY PROJECTIONS

The attempt to this point has been to say that forward planning is needed in energy fields; that projections of needs and supplies are necessary tools for deciding policies; that projections are not themselves policies or programs. It is now necessary to visualize the problems of those officials concerned with energy policy and their needs for data in order to specify the characteristics needed in the projections.

The first point is that the projections need be more explicit than energy in total. Oil companies, coal mines, pipe lines, and the Bonneville Power Administration, for example, are not satisfying total energy demands. They are concerned with particular energy commodities. Similarly, the military establishment, in planning war needs, and Interior Department, in its research and developmental activities, are concerned with specific-energy commodities. It is not very useful to know how total B.t.u. might move if the total cannot be broken into specific fuels. Moreover, the magnitude of total B.t.u. depends in part on the proportions of component energy commodities, as may be illustrated by locomotive fuel, where 1 B.t.u. of Diesel oil performed as much work as 5 B.t.u. of fuel oil in 1947.

Second, medium-term or long-range projections (1965 is used in the present study) should be so set up that it will be possible early and continuously to check and correct them and to revise the policies and programs based on them. The length of the period, the number of variables involved, the deficiencies in past and current data, and the inability firmly to predict certain elements make it impossible that all details of specific projections for 1965 should be exactly right. No projection should be an all-or-nothing proposition. It should not be necessary to wait until 1960 or 1955 to learn for the first time that a projection made in 1949 needs revision. Projections that allege to be a basis for policy decisions need built-in warning signals that flash a long time in advance in order that programs may be adjusted a long time in advance. The whole purpose of projections is to assist in anticipating and solving problems before they become crises while at the same time minimizing the cost of mistaken policy judgments.

Third, a projection should be educational beyond just furnishing end figures. Its origins should be so explicit that the policy official for whom it is prepared can bring his own judgment to bear on the major assumptions and relationships. The reason is not only that the policy official can offer constructive criticism, but also that the forecasts of needs and supplies are not absolutes. Usually, they can enter a program only after compromise, on policy grounds, because of considerations beyond the scope of the projection. For example, the policy maker may decide that the consequences of under-construction are less onerous than those of over-construction, or the reverse, and the program should reflect this. Policies may have explicit political ends, such as national security, regional development, or expanding a market. As such considerations are likely to be submerged in the forecasting process, the policy maker should understand the assumptions and their political implications sufficiently to use the forecast wisely.

Finally, economic projections should have technical characteristics of the type familiar to the economist or other statistician. Chiefly, assumptions should be explicitly stated so as to arouse constructive criticism; the functional relationships should be, in so far as possible, particular and meaningful causal relations of the type on which specialist (e.g., the fuel technologist) knowledge can be brought to bear; the deficiencies in basic data and techniques should be exposed to the extent possible; and the projections should, as a by-product, indicate the new data and analyses needed to remedy deficiencies.

PRELIMINARY EXAMINATION

At the beginning of this inquiry several aggregative statistical relationships were studied. The relationships are described here for three reasons: they are informative in themselves; they introduce the more elaborate method used later; and, finally, they exemplify the methods used in virtually all of the published energy projections.

A. Total Energy

The simplest relationship is the movement of a total-energy series through time. Chart A3/ shows the Bureau of Mines series of primary mineral fuels and water power produced and imported. The total curve rises over time, but the movement is quite erratic, and the period 1928 to 1939 shows no net increase.

The individual primary energies are also shown on the chart. The movements of each differ from those of total B.t.u., and one gets the impression that the interrelations of the components, which together form the total, are complex. Forecasts can be made from these curves by extending various trend lines. However, it is difficult to give them a rationale without a detailed explanation of why the particular past movements took place and why these movements might continue in the future. The inconstancy and uncertainty in the trends are such that one is likely to find that trend extrapolations of the separate components to, say, 1965, give values that add to a figure different from extrapolations of the "trend" of the total.

One potentially important influence is population growth, which historically has been uneven in numbers and in rate. On the hypothesis that this could explain all or part of the movement of the energy curves, the total B.t.u. series is divided by population. The curve in chart B results. This states that B.t.u. per capita rose until about 1918, fluctuated at and below this level until 1941 (i.e., for more than 20 years), and then rose again during the early years of the war. The chart B curve, flatter than the total curve in chart A, indicates that, in fact, a major part of the secular

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3/ Chart and table explanations appear at the beginning of the appendix; the charts appear at the end of the appendix.

growth in total B.t.u. is associated in time with population growth, but that a considerable part of B.t.u. variation is associated with other variables. If the individual energy items were shown on a per-capita basis, the two coal curves will be falling and the other items rising.

The hypothesis set up is then about as follows: Energy is an item in the bill of materials for the Nation's "physical" output of goods and services (gross national product, in constant prices). The aggregate amount of energy used is therefore determined by the level of economic activity. If this hypothesis is valid, it will be found that the B.t.u. time series tends to vary with the time series of national product. (This comparison can be made with either total or per-capita series). Comparison of charts B and C shows that, in fact, the B.t.u. series and the national product series vary together.

These data are now translated into B.t.u. per unit of national product, on the analogy of tons of coke per ton of pig iron, or tons of coal per gross ton mile of freight, or pounds of coal per kw.-hr. Chart D shows the result.

There appears something which, if noticed before has not been discussed in publications, and which may be at variance with general belief: Total B.t.u. per unit of national product has, with good persistence, fallen during a period of about 35 years. A trend line, fitted by least squares to the years 1924-40, 1947, indicates that the rate of fall has been slightly under 1 percent per year, compounded. In the war years the ratio B.t.u. per unit of national product fell sharply, but this was a period of restricted civilian use of energy and of unusual national product composition. Similarly, the fact that the 1947 ratio bounces back to the level of 1939 does not necessarily discredit the relationship. The record of downdrift is a long but irregular one, and 1947 may have been unusual in that it was a postwar year in which, for example, coal exports were abnormally high and improperly cleaned coal entered the market.

The tentative judgment that might be made from the chart is this: Although the level of energy requirement is primarily determined by national product level, it is subject to secular fall because of efficiency gains in energy utilization. Advances in combustion efficiency, use of insulation, use of higher temperatures, etc., occasion the downdrift. The tentative judgment is made, from knowledge that the most modern equipment is much more efficient than the average in use, that the downdrift will continue.

B. Individual Primary Supplies Per Unit of National Product

When the separate relationships of bituminous coal and anthracite, crude oil, natural gas, and hydro power per unit of national product are considered a complex situation becomes apparent (chart E). The bituminous-coal series falls persistently, at a faster rate than total B.t.u. Anthracite also falls persistently, at a faster rate than bituminous coal. Crude oil, after rising in the early years, levels off at about the point reached in the early 1930's, but the curve is quite erratic. Natural gas is level until 1920, rises sharply until 1930, and rises gradually to the present. Water power, which is converted from kw.-hr. to B.t.u. at a falling B.t.u. value through time, fluctuates erratically but appears to be roughly horizontal.

The clear indication is that some of the primary supplies are substituting for others. In projecting individual supplies, it will be useful to consider how far energy supplies are substitutable.

Their competitiveness is of two general types. One type is substitutability of finished energy commodities in use. Bituminous coal, anthracite, natural or manufactured gas, coke, fuel oil, or electricity can be, and all of them are to a substantial extent, used for heat. All of the mineral fuels except gas are used for bunker fuel; and all these, plus electricity, are used for locomotive drive. Substitutability in use characterizes perhaps two-thirds of the total supply of final energy products. The only significant areas of relative noncompetitiveness of finished energy commodities are electricity (about 14 percent of total energy supply), gasoline for motor transport and aircraft (about 10 percent), and coke and natural gas for blast furnaces and carbon black, respectively (about 5 percent).

In addition, there is substitutability in source, and this makes the primary energy sources competitive to the extent of more than 90 percent of supply. Electricity, for example, can be produced from coal, oil products, gas, or hydro-developments. Gas can be produced from any fuel. And, since the successful development of synthetic oil processes in Germany and England and the recent improvements by the Bureau of Mines in the United States, large-scale gasoline and other liquid-fuel output can be derived from coal, oil shale, and natural gas as well as from petroleum.

This might be summarized this way: The economy's functional requirements for energies could be satisfied with a variety of energy commodity combinations. These commodities could themselves be produced from a variety of domestic natural resources and imports. Therefore, as a practical matter, projections have to be made for all the energy supplies simultaneously, as each projection depends on the others.

CRITICAL EXAMINATION

The situation is not nearly as simple as a gradual and steady downdrift of energy per unit of national product, from gains in efficiency of combustion or other conversion. In fact, produced and imported B.t.u. per unit of gross national product (GNP) is not the same as coke per ton of pig iron or coal per ton-mile of freight hauled by coal locomotives. The B.t.u. aggregates, the total and the individual ones, and the national product aggregate are substantially unhomogeneous.

For example, crude oil is not used as such. Its B.t.u. mean, in final use, such unlike things as gasoline for motor cars, fuel oil for house heat and steel furnaces, Diesel oil for locomotives, lubricating oil, chemical raw materials, and exports of various refined products. Are these additive? Can hydro-electric B.t.u. for aluminum reduction and coal B.t.u. for home heating be subjected to simple addition? When 1 Diesel oil B.t.u. in locomotives displaces 7 coal B.t.u., is it safe to project a gradual downdrift from a pre-Diesel period? An oil or a gas B.t.u. in an industrial furnace produces just about as much steam as a coal one, but in a home furnace the purchase of about 8 B.t.u. of oil or gas displaces about 10 B.t.u. of hand-fired coal. How significant is this in the relationship? To what extent have substitutions of Diesel oil, fuel oil, and natural gas for coal accounted for the downdrift, and how long could such substitutions continue? To furnish consumers with a B.t.u. of net output, the oil industry consumes or loses about 15 times as much energy as the coal industry. This is also hidden in the over-all relationship. Exports of coal, oil, etc., are in the series. How have variations in these affected the ratio of B.t.u. produced and imported to national product?

Energy is a complex abstraction. Despite the attractiveness of B.t.u. conversion factors, B.t.u. are essentially measures of work and not of physical quantity, and the amount of work a fuel performs depends on the function to which it is put and the equipment in which it is used. A barrel of fuel oil, for example, which represents 6 million B.t.u. of potential useful work, would produce about 3-1/2 million B.t.u. of useful home heat, or under 1/2 million B.t.u. of locomotive work, or 1-1/2 million B.t.u. of electric power.

The only way to avoid such a dilemma is to estimate fuel need only after identifying the function and type of the equipment used. To do this, it would be necessary to build up to supplies projections from prior projections of B.t.u. of work required in particular functions or uses. This would also make it possible to appraise and to take statistical account of the causal factors that bring about change. Finally, this process would resolve the superficial paradox of finding, after a decision that individual energy supplies must be projected simultaneously in view of their interdependence, that as supplies to consumers they are too unhomogeneous in their own characteristics and the uses to which they are applied to project as a single aggregate.

The national product aggregate has its own limitations as it is used here. The B.t.u. for any given size of national product depends on the "product mix" of the national product. If other things were equal, for example, an economy producing a million tons of primary aluminum and no copper would consume 15 or 20 billion kw.-hr. more than one producing a million tons of primary copper and no aluminum. (If generated by utilities from coal at 20 percent efficiency, 20 billion kw.-hr. consumed would mean about 15 million tons of coal burned at central stations.) Or, as another example, air-conditioning in a future economy might be the equivalent in national product terms of large and well-furnished public parks, but the electrical energy required could differ by 50 million kw.-hr. Or, again, the size of national product does not closely specify the relative volumes of railroad vs. aircraft travel, but these relative volumes do affect the level of energy need.

REVISED JUDGMENT

Projection of the simple relationships in chart E implicitly assumes that a past unspecified but complex set of changing relationships will be exactly duplicated in the future, or that the net effect of these in specific energies will be duplicated. For short period forecasts from a "normal" situation, this could be a valid assumption. For a projection to 1965 from 1947, for which the immediate history includes a major depression, a war, and post-war abnormalities, it is a dubious assumption.

We revise the former tentative judgment: The downdrift in total B.t.u. per unit of national product and the differing movements of the individual energies per unit of national product are composites of several influences:

(a) Technical advance in utilization of each energy commodity in each of various industries and functions.

(b) Substitutions among the finished energy commodities and among the primary sources.

(c) Changes in "product mix" of national product resulting from changes in final demand and from changes in production techniques throughout the economy.

We observe that if we are to handle these variables adequately, it will be necessary to deal, so far as is possible, with functionally homogeneous data in order to arrive at understanding of causality in the past relationships and in order to bring engineering and scientific information to bear on item (a) and to a lesser extent (b) and (c), above.

CLASSES AND MEASUREMENTS OF ENERGY SUPPLIES AND USE

At this point it will be useful to examine the published information and to see how this information can be treated to arrive at relatively more homogeneous classifications and measurements.

A. Individual Supply Figures

Energy production and import data for 1947 are shown in table 1.

TABLE 1. - Energy produced and imported, 1947, in 10^{12} B.t.u.

Industry	Produced	Imported	Total
Bituminous coal	16,532	8	16,540
Anthracite	1,556	-	1,556
Crude oil	11,142	585	11,727
Natural gas	6,074	-	6,074
Natural gasoline and allied products ...	610	-	610
Coke ovens	2,589	3	2,592
Manufactured-gas plants	507	-	507
Refineries	11,531	371	11,902
Electric utility power (at 17,065 B.t.u. per kw.-hr.)	4,364	22	4,386
Total	54,905	989	55,894

It is obvious that the totals reflect considerable double counting. For example, the B.t.u. value of the natural gasoline is represented in natural gas, natural gasoline, and refinery outputs. Similarly, most of the electric power is produced from fuels shown separately in the table. (In addition, there is a defect in that a significant "output", industry-generated electricity and direct drive power, is not shown at all.)

B. Primary Supply

The simplest way to avoid double counting is to measure the energies at their very first appearance and to ignore energies later produced from these. Thus, a table of primary sources for 1947 can be constructed (table 2).

TABLE 2. - Energy produced and imported, 1947, in 10^{12} B.t.u., by primary sources

Industry	Produced	Imported	Total	Percent of total
Bituminous coal	16,532	8	16,540	44
Anthracite	1,556	-	1,556	4
Crude oil	11,142	585	11,727	31
Natural gas	6,074	-	6,074	16
Natural gasoline	np	-	-	-
Coke ovens	np	3	3	-
Manufactured-gas plants	np	-	-	-
Refineries	np	371	371	1
Electric power (At 17,065 B.t.u. per kw.-hr.):				
Hydro-generated	1,417	22	1,439	4
Fuel-generated	np			
Total	36,721	989	37,710	100

np = not primary.

The sums of the columns do show the supply available[4/] without double counting. And the percentages indicate that the important sources in 1947 were bituminous coal, crude oil, and natural gas, in decreasing order of importance. Unfortunately, this presentation does not characterize the specific forms of the energy commodities as consumed - these are not uniformly the energies that go to ultimate consumers. For example, blast-furnace consumption of coke, steel mill consumption of electricity, railroad consumption of Diesel oil, etc., cannot be matched up with this table; and, practically speaking, the only consumer of crude oil is refineries.

[4/] This is greater by about 1,700 x 10^{12} B.t.u. than the only published series on total energy, the Bureau of Mines "Annual Supply of Energy from Mineral Fuels and Water Power". The latter series excludes all imports except crude oil, whereas we have included these other imports; and the Bureau series excludes losses and waste of natural gas output of about 1,200 x 10^{12} B.t.u., whereas we have included this in the production figure.

C. Net Supply of Finished or Final Energy Products

This defect is remedied as an accountant does when preparing consolidated profit and loss statements. Transactions between energy-producing industries are traced, and all energy inputs into energy-producing industries are eliminated. This process also eliminates losses and use by the individual energy industries. It yields a table for 1947 (table 3) that distinguishes between net supply of final products available for the non-energy-producing economy and use and loss in energy-producing industries.

TABLE 3. - Energy distribution

Industry and product	In 10^{12} B.t.u.	In percent of total primary supply
Use and loss in energy-producing industries	5,530	15
Use and loss, in non-energy-producing economy, of:		
Bituminous coal	11,250	30
Anthracite	1,363	4
Crude oil (exports only)	273	1
Natural gas	2,762	7
Coke ovens, byproduct	2,056	5
Manufactured gas plants, byproduct	371	1
Refineries, byproduct	10,473	28
Electric utilities (17,065 B.t.u. per kw.-hr.) .	3,544	9
Industrial hydro (17,065 B.t.u. per kw.-hr.) ...	83	-
Total	37,710	100

In this table, refinery products share first importance with coal, and electric power is the third most important energy. A further point may now be noted. The energy industries consume or lose a significant part (15 percent) of total primary energy. Put another way, 117 percent as many energy B.t.u. are mined or imported as the non-energy-producing economy receives, this without making allowance for fuel consumption by railroads and vessels in hauling the energy supplies.

D. Classification According to Consuming Sector

Once the foregoing is done, or simultaneous with the preparation of the foregoing, it is possible to trace supplies of particular finished or final energy products to the individual sectors of the economy that consume them. This tracing process is exemplified by the form in table 4.

The result is a complete array of particular energy commodities consumed by each of the industries named at the heads of the columns or, alternatively, a complete accounting of the distribution of the supplies named in the stub to various consumers.

TABLE 4. - Energy consumption and distribution, by producer and consumer

	Consuming sectors											
Suppliers	Bituminous coal	Crude oil	Other energy industries	Ex-ports	Iron and steel	Aluminum refining	Other industrial	Railroads	Bunker	House-hold	Commercial	Others
Bituminous coal												
Crude oil ...												
Petroleum refineries:												
Gasoline ..												
Diesel oil, ...												
Others												
Electric utilities .												
Others.......												

E. Classification According to Consuming Sector and Function

The energy supplies consumed in each of the industries or other consuming sectors can then be viewed as performing a number of specialized functions. For example, it may be useful to characterize energy input in each industry as space heat, process heat, stationary electric power, stationary direct-drive power, and motive power. This yields the form shown in table 5.

TABLE 5. - Energy consumption, by consumer and function

Consumer	Total energy consumed	Heat	Stationary power	Other
Iron and steel				
Aluminum				
Households				
Bituminous coal				
Electric utilities				
Other				

F. B.t.u. Measurements of Energy

The classifications described under E, above, permit alternative B.t.u. measurements. One measurement is the theoretical B.t.u. value of each energy input. This measurement yields figures that, as primary supplies are traced to the place of final consumption, total to exactly the volume of primary supply.

From these data, however, it is possible to move to another B.t.u. measurement of consumption in each sector in each function, which might be termed "useful work" or "work." This takes into account the wide variations existing among efficiency ratios (B.t.u. of useful work ÷ B.t.u. of fuel used); for example, the ratio for automobile engines is about 18 percent; for home coal furnaces about 50 percent; for commercial building heat about 70 percent; and other examples were given earlier. It therefore changes the relative magnitudes of energy consumed in each sector and function.

This measurement also presents the discrepancy between total energy supply used and total useful work performed. Relative to the 38×10^{15} B.t.u. energy supply in 1947, for example, work produced from this supply is estimated at about 15×10^{15} if power is credited with 3,413 B.t.u. per kw.-hr., and less than 20×10^{15} B.t.u. if power is credited with 17,065 B.t.u. per kw.-hr. These represent over-all efficiency ratios of about 40 and 52 percent, respectively.

ANATOMY OF ENERGY USE, 1939 AND 1947

As just indicated, the anatomy of energy use has numerous dimensions - type of energy commodity, primary source, sector of consumption, measurement as supply or work, function to which applied, and others. Two additional examples are presented, both because they characterize important dimensions in themselves and because they help to make concrete some of the immediately preceding discussion.

Table 6 summarizes 1939 and 1947 energy use and loss, by consuming sectors, as percentages of total consumption:

TABLE 6. - Energy use and loss, by consumption sectors, (as percent total consumption)

Consumption sector	1939	1947
Energy-producing industries:		
Bituminous coal	0.4	0.4
Anthracite	.3	.2
Crude oil	.8	.8
Natural gas, natural gasoline, and allied	5.7	5.8
Coke ovens	.9	1.5
Manufactured-gas utilities	.5	.4
Petroleum refineries	3.5	4.3
Electric utilities	2.1	1.8
Total	14.1	14.7
Manufacturing (1939 census groups):		
Iron and steel	7.5	8.1
Chemicals	3.6	4.2
Textiles	1.3	1.1
Stone, clay, and glass	2.5	2.4
Food and kindred	2.3	1.9
Paper and allied	1.8	1.7
Nonferrous metals	1.0	1.3
Other manufacturing, excluding refineries and coke ovens	2.7	3.2
Total	22.6	23.9
Railroads	11.1	9.9
Bunker	2.3	2.1
Household, commercial, and other domestic fuel and power:		
Heat	24.5	21.8
Power	4.5	5.3
Motion	12.5	11.7
Total	41.6	38.7
Domestic chemical material, lubes, etc.	2.0	2.6
Exports	6.2	8.0
Total	100.0	100.0
Total in 10^{15} B.t.u.	24.0	37.6

Notes: (1) Totals will not add, owing to rounding.

(2) Power is included in terms of B.t.u. of fuel required in its production; hydro power is measured in terms of mineral fuels equivalent in each year.

(3) The discrepancy between 37.7 x 10^{15} B.t.u. energy supply in tables 2 and 3 and 37.6 x 10^{15} B.t.u. consumption in this table is primarily stock change.

It is apparent from the table that: (1) some sectors are larger consumers than others; (2) the sectors do not grow at identical rates; (3) efficiency changes in the several sectors are not likely to be uniform; and, therefore, (4) the future increases required in total energy supplies depend on individual degrees of energy intensiveness, individual rates of growth, and individual efficiency changes.

Table 7 is another approach - it presents 1939 and 1947 energy consumption by function, as percent of total supply and as percent of total work performed in the domestic economy. It may be observed from this table that what was said of sectors, growth rates, and efficiency changes in the preceding paragraph applies to functional breakdowns as well.

TABLE 7. - Energy use and loss, by function, as percent of total consumption and work, 1939 and 1947

	Percent of total consumption		Percent of total work	
	1939	1947	1939	1947
Space and process heat	53	51	86	85
Motion power	25	23	7	7
Electric power and stationary direct drive.	14	15	7	8
Domestic chemical material, lubes, etc. ...	2	3	0	0
Exports	6	8	0	0
Total	100	100	100	100
Total in 10^{15} B.t.u.	24.0	37.6	8.9	15.0

Detailed tables from which the foregoing summaries were prepared appear in the appendix. As will become apparent from the discussion immediately below, the projections are based on the more detailed data, which are classified both by sectors of consumption and function.

DESCRIPTION OF APPROACH AND METHOD

The foregoing discussion has made possible a short description of the conceptual apparatus used herein. This apparatus is a lengthy elaboration of the time-changing relationship "B.t.u. per unit of national product." It attempts to break this over-all relationship into narrow homogeneous fragments that have economic and engineering meaning. This aim is to relate quantities of energy consumed in each use to the size of the energy-consumer's activity.

A. Anatomy of Use 1939 and 1947

1. Primary energy supplies were traced through the energy-processing industries and furnished final or finished energy supplies figures. The discrepancies between total primary supply and finished supplies were charged to the energy-producing industry in which the loss or consumption occurred. Natural gas blown to air in the natural-gas and natural-gasoline industries, for example, has been charged to them.

2. Finished supplies were traced to the sectors (e.g., steel plants, households, etc.) purchasing or consuming them.

3. The quantities of these supplies that were applied in each consuming sector to each function (e.g., heat, power, etc.) were estimated.

4. Then, having regard to the particular energy commodities, the particular consuming sector, and the particular function, the data were translated into useful work, classified by sector and function.

5. The work requirement for that sector and function was conceived as depending on (a) the volume of output (or other activity) in the consuming sector and (b) the B.t.u. of work used in that function per unit of output (or other activity). Thus, the requirement for the textile industry and the power function is written:

   $$\text{kw.-hr. required (used)} = \text{textile output} \times \text{kw.-hr. required (used) per unit of textile output}$$

   And, if the power was self generated from fuel,

   $$\text{mineral fuel required (purchased)} = \frac{\text{kw.-hr. required (used)} \times 3{,}413}{\text{generation efficiency}}$$

   Or, as another example, for the paper and allied products industry and the heat function is written:

   $$\text{B.t.u. heat work required (used)} = \text{paper output} \times \text{heat required (used) per unit of paper output}$$

   $$\text{And, mineral fuel required (purchased)} = \frac{\text{B.t.u. work required}}{\text{efficiency}}$$

   The foregoing was done for each energy use by each and every consuming sector, including the energy-producing industries.

6. At this point every energy use is expressed as a function of (a) output (or other activity) of the consuming sector, (b) intensity of work per unit of output (or other activity), and (c) efficiency of converting purchased energy commodities into work.

B. Projecting Work Requirements

Future work requirements will differ from present ones only to the extent that one or more of the three variables just enumerated change. Passing the matter of conversion efficiency for the moment, the next steps, then, were to estimate changes in each of the other variables, i.e.: (a) to project a balanced structure of output (and other activity) for the United States economy in 1965; (b) to estimate the extent of change in work required per unit of output (or other activity) for each function in each sector; and (c) to arrive at estimates of 1965 work requirements by function in each energy-using sector by multiplying the 1965 outputs (or other activities) and 1965 outputs (or other activities) and 1965 work requirements per unit of each output.

This can be done in index-number form as follows: Let R = work required in a sector and function, O = output of the consuming sector, and A = work required per unit of output. Then

$$R_{47} = O_{47} \cdot A_{47}$$

and

$$R_{65} = O_{65} \cdot A_{65}$$

Multiplying right-hand member of latter equation by $\frac{R_{47}}{O_{47} \cdot A_{47}}$

gives, $R_{65} = R_{47} \cdot \frac{O_{65}}{O_{47}} \cdot \frac{A_{65}}{A_{47}}$

This states that requirement in 1965 is equal to the 1947 requirement multiplied by indexes (1947 = 100) of 1965 output and work per unit of output.

It should be noted that the outputs of the energy-producing industries are viewed as functions of the requirements for their outputs by the remainder of the economy. All the terms for the 1965 equations for the energy-producing industries are not available until the energy forms that the remainder of the economy chooses to satisfy its work requirements are specified. Immediately upon specification of these forms, and use efficiencies in 1965 relative to use efficiencies in 1947, work may be translated into energy purchased, and energy purchased into energy produced.

C. Projecting Finished Energy Commodity Supplies and Primary Sources

This gives 1965 requirements, and the particular supplies that will be produced to satisfy these needs may be projected. The following conceptual relationship between the projected functional requirements and specific fuel supplies is then appropriate: (a) Energy commodities will be efficiently produced from the least expensive sources, including imports; (b) they will be marketed at prices that just cover costs of production, including capital charges and risk charges, where these are applicable; (c) the volumes and specific forms of supplies will be determined by the purchase offers of an unregulated consumption economy. In short, the assumption is that production (carried on under minumum-cost conditions) and supply (offered at competitive prices) will be dictated by individual consumer preferences expressed through unregulated purchases. It is believed that these efficiency, price, and consumer-freedom assumptions are, in view of national anti-monopoly and other policies, the most reasonable approximations that can be made of the long-run market reality.

Estimates formed on these assumptions should be based on appropriate studies of future costs and of other factors affecting consumer preference. In certain cases, such as coke for blast furnaces, natural gas for carbon black, and gasoline for automobiles, the relatively specialized nature of the function or application dictates particular energy products. In other cases, such as locomotive fuel, one fuel (Diesel oil) has a strong present and prospective advantage over alternatives. But for the major part of total energy consumption, for which alternative commodities could be used, there is insufficient confidence in speculations on cost trends, etc., in their present state to offer calculations based on them as single estimates. Instead, except for such cases as those illustrated above, a number of alternative energy "supply baskets" are offered.

The specific assumptions on which the alternative supply patterns are based are detailed in the Appendix. These alternatives are labeled cases A, B, C, and D. Case A assumes an economy that, for price, convenience, and other considerations relevant in a free consumer-choice economy, continues present tendencies away from solid fuels in the production of heat and electric power. With respect to the displacement of solid fuel and the net growth in requirements, this economy is assumed to tend primarily to natural gas and secondarily to fuel oil. Case B is identical with case A, except that the primary tendency is to fuel oil and the secondary one to natural gas. In case C it is assumed that coal maintains its 1947 position vis-a-vis other fuels in the production of heat and electric power in the individual consumption sectors. Case D is a variant of case C; it differs only in the assumption that there will be synthetic-oil production of 65 to 70 million barrels per year from each of shale and coal, instead of an equivalent volume of crude-oil imports.

The results, after projecting energy supplies, are detailed pictures of the United States economy in which energy supplies and uses (including exports and imports) are specifically itemized. The assumptions allege that one of the patterns of energy supply suggested, or another derived from the requirements estimates, would provide (at minimum cost, including social costs and having regard to relative use-convenience of specific fuels) the energy required in a free-consumption economy for the indicated national product of that period. The implied task of policy, private and government, is, as always, to devise means for efficiently and economically providing the volumes and proportions of energy that consumer choice dictates.

FUNCTIONAL REQUIREMENTS 1965

The following conclusions on requirements are consistent with and, to a significant degree, ultimately derive from a projected increase in national output of all goods and services of about 65 percent between 1947 and 1965. The historical course of national product is shown in chart F; national product in 1965 is estimated at about $390 billions at 1947 prices.

A. Heat

The first conclusion concerns the total rate of growth in energy supplies required for heat, the chief use, which results when the supplies required for each of the specific uses is separately estimated for 1965. This growth is estimated at about 40 percent, as compared with the national product growth of 65 percent.

Table 8 presents 1965 projections, by major consuming sectors, for the four alternative cases mentioned on page 18 above, and compares these with 1947.

The effect of different patterns of supply from the energy industries is, of course, reflected in differences in heat use and loss in the individual energy-producing industries. The consumption of fuel for heat in manufacturing and railroad nonmotive use is constant for the alternative patterns because of the assumption that efficiencies of the various mineral fuels in these applications do not vary. Efficiency variations account for the alternatives in the commercial, household, and other sector.

Important differences in rate of growth may be noted among sectors of consumption. Except for the very large estimated growth in chemicals-industry output and this sector's fuel consumption, for example, estimated growth of fuel consumption for heat in manufacturing would have been only 48 percent instead of 58 percent. The fact of lesser relative growth in heat consumption and loss in the energy industries stems in good part from a decrease in the relative volume of vented natural gas. It will be noted that the rate of increase in industry fuel consumption is greater than in home or commercial application.

It is believed that the aggregate rate of growth projected is too high owing to inability to separate the whole of the "household" component from the "commercial, household, and other" sector. The "household - unidentified, commercial, and other" sector has been projected as if it did not include household at all; this significantly overstates the fuel requirement, as household demand for fuel grows less rapidly than commercial demand. The 1950 Census will permit improving this portion of the projection.

The prime element that accounts for less rapid increase in mineral-fuels consumption for heat than in national output is technological advance in energy utilization efficiency. This influence toward decrease in fuel supply for heat per unit of output is subject to offset by those changes in production techniques, product innovations, and change in the composition of the national output that might work to increase fuel for heat per unit of national output. The rapid gorwth in chemicals-industry output cited, is one example of such offset influence. According to these estimates, data on which appear in the Appendix, these influences will fall short of fully offsetting even the moderate gains in efficiency in heat production - averaging in the neighborhood of 10 percent of present efficiencies - which are projected between 1947 and 1965.

TABLE 8. - Fuels for heat - consumption and loss, by consumer, 1947 and 1965, in 10^{12} B.t.u.

	1947	Case A	Case B	Case C	Case D	Percentage increase, 1947 to 1965
Energy-producing industries:						
Bituminous coal	38	32	32	45	47	-16 to +24
Anthracite	41	19	19	30	30	-54 to -27
Crude oil	243	308	308	308	308	27
Natural gas and allied	1,839	2,973	2,200	1,594	1,594	-13 to +62
Coke ovens	540	726	726	731	731	35
Manufactured-gas utilities	119	96	96	118	118	-19 to - 1
Petroleum refineries	1,500	2,109	2,109	1,928	1,816	+21 to +65
Synthetic oil plants	0	0	0	0	654	-
Total	4,320	6,263	5,859	4,754	5,298	+10 to +45
Manufacturing (1939 census groups):						
Iron and steel	2,533		3,774			49
Chemicals	1,152		2,383			107
Textiles	221		302			37
Stone, clay, and glass	750		1,117			49
Food and kindred	515		674			31
Paper and allied	375		559			49
Non-ferrous metals	204		305			49
Other manufacturing, excluding refineries and coke ovens	744		1,153			55
Total	6,494		10,267			58
Railroad-non motive	393		540			37
Commercial, household, and other:						
Identified as household	2,243	2,325	2,338	2,397	2,397	+ 4 to + 7
Household-unidentified, commercial, and other	5,939	8,521	8,592	8,855	8,855	+43 to +49
Total	8,182	10,846	10,930	11,252	11,252	+33 to +38
Grand total	19,389	27,916	27,596	26,813	27,357	+38 to +44

Note: Totals may not add owing to rounding.

B. Motion

The second conclusion is the startling one (at first sight, at least) that total fuels required for motive power, the next largest application, will be approximately the same in 1965 as in 1947. This net resultant is compounded of diverse individual elements, as in the case of heat. Table 9 presents the 1965 projections and the percentage changes from 1947. Dieselization of railroads and moderate efficiency gains in use of motor fuel offset entirely the increases in work requirements of railroads, ships, highway vehicles, etc.

The locomotive fuel alternatives result from the fact that the relatively larger volume of the Nation's coal production in cases C and D, as compared with cases A and B, change the projection of 1965 rail tonnage moved. The increase in 1965 locomotive work over 1947 locomotive work is 44 percent in cases A and B and 52 percent in cases C and D.

C. Power

The third conclusion is that the next largest use, electric and stationary direct drive power, will increase by about 60 percent in terms of fuel required for its generation[5] between 1947 and 1965. In terms of kw.-hr. this represents an increase of about 140 percent. This category of consumption is thus expected to increase significantly more, percentage-wise, than fuel consumption for heat or motion.

Table 10 presents the estimated 1965 consumption of power, by consuming sectors, in terms of fuels required to generate the power. It also indicates the percentage increase over 1947, expressed in terms of fuel required for generation and in terms of kw.-hr. The four cases are shown separately in the Appendix; here are shown only ranges.

A major point to be noted is that advance in central-station efficiency, estimated to average 30 percent in 1965 as compared with 20 percent in 1947, converts a sharp increase in requirements for power into a moderate increase in requirements for primary energy resources.

Another major point is the reflection in the table that the growth in power demand is highly uneven as among the various sectors of consumption. If these estimates are valid, the household, commercial, and electroprocess sectors are of prime significance in accounting for the growth in total power demand.

5/ If hydro is measured in terms of B.t.u. of mineral fuels at the average thermal central station efficiency at each date.

TABLE 9. - Fuels for motion - consumption and loss, by consumer, 1947 and 1965, in 10^{12} B.t.u.

	1947	Case A	Case B	Case C	Case D	Percentage increase, 1947 to 1965
Railroad locomotives:						
Coal	2,631	832	832	1,055	1,055	-68 or -60
Fuel oil	563	0	0	0	0	-
Diesel oil	104	638	638	638	638	514
Gasoline	2	1	1	1	1	0
Electricity (included in "stationary power")						
Total	3,299	1,471	1,471	1,694	1,694	-55 or -49
Bunker:						
Coal	78	67				-15
Fuel oil	644	644				0
Diesel oil	81	224				178
Total	803	935				16
Motor fuel:						
Cars	2,512	2,994				19
Other highway use	1,015	1,397				38
Aviation	113	600				429
Other non highway use	529	698				32
Total	4,169	5,689				36
Tractor fuel - kerosene and diesel only	71	181				156
Army, Navy, Coast Guard, Diesel and fuel oil only	151	151				0
Grand total	8,493	8,426	8,426	8,650	8,650	- 1 or + 2

Note: Totals may not add owing to rounding.

TABLE 10. - Fuels for power - consumption and loss, by consumers, 1947 and 1965, 10^{12} B.t.u.

	1947	1965	Percentage increase in B.t.u. fuel over 1947	Percentage increase in kw.-hr. over 1947
Energy-producing industries:				
Bituminous coal	97	99-145	2-50	53-124
Anthracite	36	28-46	-20-+28	20-93
Crude oil	66	101	53	130
Natural gas and allied	129	113-212	-12-64	32-147
Coke ovens	33	30	-9	37
Manufactured-gas utilities	33	16-20	-51--40	-27--10
Petroleum refineries	135	144-197	6-45	60-118
Electric utilities	682	1,248-1,258	82-84	174-176
Total	1,211	1,847-1,912	53-58	129-137
Manufacturing (1939 census groups), excluding refineries and coke ovens:				
Electroprocess (S.I.C. and 1947 census four-digit classes):				
Abrasive products-3291	5	9	96	195
Electrometallurgical products-3313	84	208	148	272
Primary nonferrous metals, nec-3339	1	2	313	519
Alkalies and chlorine-2812	51	78	53	130
Inorganic chemicals, nec-2819	79	155	97	195
Total (part of 1939 census chemicals group	218	451	107	210
Electrosteel-part of 3312	38	96	153	280
Electric heat treating-no number	85	131	53	130
Total (treated as part of 1939 I and S group)	123	226	84	176
Primary aluminum-3334	178	414	133	250
Primary zinc-3333	23	37	62	143
Primary copper-3331	13	12	-3	46
Aluminum rolling and drawing-3352	17	39	133	250
Copper rolling and drawing-3351	17	26	53	130
Total (part of 1939 nonferrous group)	246	528	114	221
Carbon and graphite products-3612	9	21	140	260
Total, electroprocess	597	1,227	106	209
Other manufacturing (1939 census groups):				
Iron and steel group	389	428	10	65
Chemicals group	225	346	53	130
Textiles group	175	177	1	52
Stone, clay, and glass group	149	164	10	65
Food and kindred group	185	217	17	75
Paper group	279	306	10	65
Nonferrous group	31	34	10	65
Other manufacturing groups	467	803	72	158
Total, Other manufacturing	1,899	2,474	30	95
Total, Manufacturing, excluding refineries and coke ovens	2,496	3,701	48	122
Railroads:				
Locomotives	37	41	10	65
Nonmotive	7	11	52	128
Total	45	52	17	75
Household, commercial, and other:				
Household	849	1,783	110	215
Street and interurban railway	77	68	-12	33
Public authorities; street and highway lighting	151	249	65	148
Commercial	737	1,288	75	162
Other	162	173	7	60
Total	1,975	3,559	80	170
Total electric and stationary direct-drive power	5,726	9,160-9,225	60-61	140-142

Notes: 1. Totals will not add owing to rounding.
2. Power is measured as 17,065 B.t.u. per kw.-hr. in 1947 and 11,377 B.t.u. per kw.-hr. in 1965.

The conditional character of our projections is illustrated by the figures for power consumption in the electroprocess industries and in household use. The electroprocess consumption and, to a less extent, the household consumption depend on the availability of a rapidly expanding, relatively low-cost power supply. The 1965 household figure, for example, averages between 3,000 and 4,000 kw.-hr. per residential customer, a level of consumption that in 1947 was exceeded in parts of the Bonneville Power Administration, TVA, and Niagara Falls areas, but which was equaled nowhere else.

D. Chemical Materials, Lubes, etc., and Exports

Table 11 presents projections of 1965 domestic consumption of coke-oven tar and oil and of petroleum refinery products not consumed in the production of heat, motion, or stationary power. They are stated, for convenience, in terms of B.t.u. so that they may be merged with the other energy-consumption data and because they had to be so measured to trace them back to primary sources, but their B.t.u. content is largely irrelevant to their use:

TABLE 11. - Domestic consumption of chemical materials, lubes, etc., 1947 and 1965 in 10^{12} B.t.u.

	1947	1965	Percentage increase, between 1947 and 1965
Coke-oven tar and oil	70	115	65
Manufactured gas utility tar and oil	34	28-33	-17-0
Refinery products - lubes, wax, asphalt, road oil, misc.	866	1,452-1,457	68
Total	969	1,600	65

The projections were needed to round out total energy demand and supply. They are not based on careful study and the most that can be said for them is that they are reasonable in relation to 1947 consumption and in relation to the major product outputs in 1965 of their producing industries.

The export data in table 12 reflect the estimated shift in the ability of domestic companies to compete in foreign markets in 1965 as compared with 1947. In part, this shift is merely a departure from the abnormal foreign demand for U. S. coal and oil which prevailed in postwar 1947, and in part it is due to the projected development of foreign energy resources.

The projections for 1965 are preliminary estimates of the actual 1949 exports, with the exception that no exports of crude oil and natural gas are projected.

TABLE 12. - Energy exports, 1947 and 1965, in 10^{12} B.t.u.

	1947	1965	Percentage change between 1947 and 1965
Bituminous coal	1,801	730	-60
Anthracite	232	134	-42
Crude oil	278	0	-
Natural gas	18	0	-
Coke	22	14	-34
Refinery products:			
Motor fuel	250	208	-17
Kerosene	41	14	-35
Diesel and other gas oil	177	72	-59
Residual fuel oil	67	80	+19
Coke	13	15	+18
Miscellaneous	13	9	-31
Lubricants	86	79	- 9
Wax	6	6	- 6
Asphalt	21	10	-52
Total	3,025	1,371	-55

E. Total

The fifth observation results from adding the fuel requirements for heat, motion, power, chemical materials, and exports. The total B.t.u. of energy supply required to satisfy all 1965 demands is estimated at slightly less than 30 percent more than the 1947 supply. (If 1965 hydro were weighted at the average mineral fuel value per kw.-hr. prevailing in central stations in 1947, rather than that expected to prevail in 1965, the growth would be slightly more than 30 percent.) The slow rates of increase in demand for fuels for motion and heat and the decline in exports significantly offset the more rapid rate of increase in demand for fuel for electric and stationary direct-drive power.

The estimated increase in total energy supply required is only about half the increase in national produce. Or, put another way, if the B.t.u. supply per unit of national product in 1947 is conceived to be 100, then the comparable figure estimated for 1965 is only about 78.

Note that the preliminary examination, presented earlier, suggested the possibility of a fall in the ratio of B.t.u. to GNP. The rate of fall in the ratio just calculated from the detailed structure of analysis is somewhat faster than a simple trend extrapolation from the 1947 level. That the fall in the ratio will continue is significant, but it is more important that this method of analysis indicates why. It is, perhaps, significant, too, that on the basis of this understanding, under certain circumstances in which interest is focused on total energy supply from natural resources, one of the end results of detailed analytic projection can be approximated by trend extrapolation of the B.t.u./GNP ratio.

Table 13 summarizes consumption of 1947 and 1965 energy supply for all functions, by consuming sectors. To simplify the presentation, only the case A projection is shown. The other cases are much the same in the non-energy-producing sectors.

The differences in growth of energy consumption may be noted. Manufacturing consumption grows faster than consumption (including exports) in the economy as a whole. Chemicals and nonferrous metals are estimated to be the most rapidly growing manufacturing sectors in terms of energy consumption. Power is the most rapidly growing household, etc., sector. The projected declines in railroad consumption and exports are large and are significant in holding down aggregate increase in fuel requirements.

TABLE 13. - Total energy consumed, by consumer, 1947 and 1965

	1947		1965 (case A)		Percentage increase between 1947 and 1965
	In 10^{12} B.t.u.	Percent of total	In 10^{12} B.t.u.	Percent of total	
Energy-producing industries	5,531	14.7	8,175	16.8	48
Manufacturing (1939 census groups):					
Iron and steel	3,045	8.1	4,428	9.1	45
Chemicals	1,596	4.2	3,180	6.6	99
Textile	396	1.1	479	1.0	21
Stone, clay, glass	899	2.4	1,281	2.6	42
Food and kindred	700	1.9	891	1.8	27
Paper and allied	654	1.7	865	1.8	32
Nonferrous metals	481	1.3	867	1.8	80
Other manufacturing	1,220	3.2	1,977	4.1	62
Total	8,990	23.9	13,968	28.8	55
Railroads	3,736	9.9	2,063	4.3	-45
Bunker	803	2.1	935	1.9	16
Household, commercial, and other domestic fuel and power:					
Heat	8,182	21.8	10,846	22.3	33
Power	1,975	5.3	3,559	7.3	80
Motion	4,391	11.7	6,021	12.4	37
Total	14,548	38.7	20,426	42.1	40
Domestic chemical materials, lubes, etc. .	969	2.6	1,372	2.8	42
Exports	3,025	8.0	1,600	3.3	-47
Total	37,602	100.0	48,539	100.0	29

Notes: 1. Totals will not add owing to rounding.

2. Power is included in terms of B.t.u. of fuel required in its production; hydro power is measured in terms of mineral fuels equivalent.

The "percent of total" columns also disclose the differential growth rates. They show manufacturing and household, commercial, and other increasing at the expense of exports and railroad consumption.

F. Main Influences

The decline in total B.t.u. per unit of national product between 1947 and 1965 stems in part from normal increases in efficiency of fuel utilization. These are the consequences of technical advances in combustion, use of more efficient temperatures and pressures, extensions of insulation practices, and substitution of modern types of fuel-economical equipment and processes for existing ones. The chief case of substitution is Diesel locomotives.

In the projections, no engineering practice not already perfected was considered. Some account was taken of the fact that a sustained increase in national product in a full employment economy facilitates the introduction of modern, efficient equipment. Insufficient account was taken, it is believed, of the fact that 1947, the year from which the projections were made, was a time when all capacity, no matter how inefficient and over-age, was pressed into use to produce for a seller's market.

The decline in total B.t.u. per unit of national product derives very substantially, also, from the fact that significant sectors of energy demand depend on growth influences, such as population and foreign markets, which are not subject to the rapid increases of national product.

There are, as was noted, factors offsetting these tendencies to fall in the ratio of B.t.u. to GNP. Chief among these are the very rapid rate of growth in demand for electric power, and some shift in the composition of GNP in the direction of energy-intensive commodities, such as products of the chemicals industries.

SUPPLIES PROJECTIONS, 1965

Table 14 presents 1947 and projected 1965 energy outputs at all stages of supply, classified by producing industries. These data are not additive, as some of the outputs are derived from sources shown separately. Electric utility power and hydroelectric power show large relative increases in all four cases. In cases A and B, natural gas commodities and petroleum products experience large relative increases, while coal supply and manufactured gas output decline. In cases C and D output of bituminous coal increases substantially, and outputs of oil and natural gas increase by lesser percentages.

Table 15 presents similar information, but the energy industries' own use and losses are excluded in this table. The data show, therefore, the amount of each energy form consumed by the non-energy-producing economy. As double counting from converting, say, coal to coke to gas, etc., is eliminated, the remainders are additive and show energy consumed by the non-energy-producing economy classified according to final form or source.

TABLE 14. - Energy production, by industries, 1947 and 1965, in 10^{12} B.t.u.

	1947	1965			
		Case A	Case B	Case C	Case D
Bituminous coal, domestic	16,532	13,720	13,709	19,658	20,383
Imports	8	0	0	0	0
Total	16,540	13,720	13,709	19,658	20,383
Anthracite	1,556	1,000	1,000	1,606	1,606
Shale ore production	0	0	0	0	727
Crude oil, domestic	11,142	15,000	15,000	15,000	15,000
Imports	585	2,375	5,361	911	0
Total	11,727	17,375	20,361	15,911	15,000
Natural gas, before scrubbing	6,074	13,028	9,716	7,009	7,007
Natural gasoline and allied products	610	1,500	1,100	702	702
Coke oven products:					
Domestic	2,589	3,459	3,459	3,482	3,482
Imports	3	0	0	0	0
Total	2,592	3,459	3,459	3,482	3,482
Manufactured gas utility products	507	376	376	463	463
Petroleum refineries:					
Domestic	11,531	16,214	19,050	14,823	13,957
Imports	371	0	0	0	0
Total	11,902	16,214	19,050	14,823	13,957
Synthetic oil from shale and coal	0	0	0	0	799
Electric utility power:					
Domestic	4,364	8,087	8,068	8,026	8,022
Imports	22	0	0	0	0
Total	4,386	8,087	8,068	8,026	8,022
Hydroelectric power, total	1,419	3,413	3,413	3,413	3,413
Industry-generated electric and stationary direct-drive power	1,362	1,138	1,138	1,138	1,138

Note: Power is included at 17,065 B.t.u. per kw.-hr. in 1947 and 11,377 B.t.u. per kw.-hr. in 1965.

TABLE 15. - Consumption by the non-energy-producing economy of energy products, in 10^{12} B.t.u.

	1947	1965			
		Case A	Case B	Case C	Case D
Bituminous coal	10,558	6,403	6,403	11,268	11,268
Anthracite	1,363	981	981	1,576	1,576
Petroleum refineries	10,384	15,138	17,358	13,705	12,906
Synthetic-oil plants	0	0	0	0	799
Natural gas	2,655	7,393	5,257	3,924	3,924
Manufactured-gas utilities	371	300	300	370	370
Electric utilities	3,544	6,551	6,551	6,551	6,551
Non-energy-industry self generated power	971	762	762	762	762
Coke ovens	2,056	2,836	2,836	2,836	2,836
Crude oil (exports)	278	0	0	0	0
Total	32,180	40,364	40,448	40,992	40,992

Note: Power is included at 17,065 B.t.u. per kw.-hr. in 1947 and 11,377 B.t.u. per kw.-hr. in 1965

The following points may be noted. First, total energy consumption of the non-energy-producing sectors increases by 25 to 27 percent, a rate slightly lower than the increase in consumption of the economy as a whole. Second, the importance of increased electric utility output to maintaining coal consumption is illustrated in cases A and B by the sharper fall and in cases C and D by the slighter rise in coal consumed by the non-energy-producing economy, as compared with coal consumed in the economy as a whole (see table 14). Third, the percentage increase in natural gas consumption by the non-energy-producing economy is greater than the percentage increase by the economy as a whole because of the expected decrease in the proportion of gas vented, a loss which in our data is classified as consumption by the natural-gas industry.

Tables 16, 17, and 18 present 1939, 1947, and projected 1965 energy supplies by natural-resource origin.

TABLE 16. - Energy production, by primary sources, 1939, 1947, and 1965, in 10^{12} B.t.u.

Primary energy source	1939	1947	1965 Case A	1965 Case B	1965 Case C	1965 Case D
Bituminous coal	10,298	16,532	13,720	13,709	19,658	20,383
Anthracite	1,400	1,556	1,000	1,000	1,606	1,606
Petroleum:						
Domestic	7,590	11,142	15,000	15,000	15,000	15,000
Imports	354	956	2,375	5,361	911	0
Natural gas	3,399	6,074	13,028	9,716	7,009	7,007
Hydro	875	1,417	3,413	3,413	3,413	3,413
Coal, coke, and power imports.	56	33	0	0	0	0
Shale ore	0	0	0	0	0	727
Total	23,972	37,710	48,536	48,199	47,597	48,136

Note: Hydro and imported power are included as 18,340 B.t.u. per kw.-hr. in 1939, 17,065 B.t.u. per kw.-hr. in 1947, and 11,377 B.t.u. per kw.-hr. in 1965.

TABLE 17. - Energy production, by primary sources, as percent of total, in 1939, 1947, and 1965

Primary energy source	1939	1947	1965 Case A	1965 Case B	1965 Case C	1965 Case D
Bituminous	43	44	28	29	41	42
Anthracite	6	4	2	2	4	3
Total	49	48	30	31	45	45
Petroleum:						
Domestic	32	30	31	31	31	31
Imports	1	2	5	11	2	0
Total	33	32	36	42	33	31
Natural gas	14	16	27	20	15	15
Hydro	4	4	7	7	7	7
Shale ore	0	0	0	0	0	2
Total	100	100	100	100	100	100

Note: Hydro is included as 18,340 B.t.u. per kw.-hr. in 1939, 17,065 B.t.u. per kw.-hr. in 1947, and 11,377 B.t.u. per kw.-hr. in 1965.

TABLE 18. - Energy production, by primary sources, in conventional units, in 1939, 1947, and 1965

Primary energy source	1939	1947	1965			
			Case A	Case B	Case C	Case D
Bituminous coal, MM tons	393	631	524	523	750	778
Anthracite, MM tons	51	57	37	37	59	59
Petroleum, MM bbl:						
Domestic crude	1,265	1,857	2,500	2,500	2,500	2,500
Imported crude and refined	59	159	396	894	152	0
Shale, MM tons	0	0	0	0	0	182
Natural gas (wet), MMM cu. ft. ..	3,162	5,650	12,119	9,038	6,520	6,518
Hydro, MMM kw.-hr.	48	83	300	300	300	300

Coal production declines in cases A and B. Even in cases C and D, which implicitly assume a reversal of past and present tendencies with respect to coal's competitive ability, the rise in coal output is not large.

The conspicuous relative increases are in hydropower, natural gas, and petroleum. The hydropower of 300 billion kw.-hr. in 1965, 3-1/2 times the 1947 level, is a judgement that something like this volume of development, assuming multipurpose projects where feasible, could take place on cost grounds in response to the contemplated increase in power requirements at such costs. The current rate of hydrodevelopment, it may be noted, is substantially below the rate implicit in 300 billion kw.-hr. per year output in 1965. The domestic crude-oil and natural-gas figures in cases A and B are consistent with the available evidence on reserves and rate of new findings. The substantial increase in crude-oil imports in cases A and B rest on the combined grounds of delivered cost to the consumer and American company ownership of important foreign reserves.

It will be noted that our supply estimates do not include solar energy or atomic energy. We have considered these possibilities and find it difficult to see how either could grow to significant volumes, relative to total energy supply, by 1965. If, for example, 10 percent of the electric power added between 1947 and 1965 were provided by atomic stations, atomic energy would provide about 1 percent of the total energy supply of 48×10^{15} B.t.u. Our omission is a statistical convenience assumption, of course, and has no bearing on the current policy question of how fast atomic power should be developed.

ASSUMPTIONS, QUALIFICATIONS, AND STATISTICAL NOTE

Although most of the major assumptions were stated in the preceeding text or are discussed in the appendix, two will be mentioned explicitly at this point. First, despite the repeated reference to the 65 percent increase in national product, the projections would not hold for all years in which national product was 65 percent greater than 1947. Rather, the projection is made for a year in the immediate vicinity of 1965 and a national product increase of 65 percent. The reason is that variables other than national product have entered the projections, and most of these are tied wholly or partly to the passage of time. Among these are technical advances in efficiency of utilizing energies, growth in population and families, feasible rates for construction of hydro facilities, rates of displacement of existing energy using capital such as locomotives and houses, and growth in demand for products of the electro process and chemical industries. Second, it was assumed at various points in the estimates that there would be relatively full employment and peace during the entire growth period.

As stated earlier, the data presented here are preliminary. Revision will result from (a) utilizing the 1947 Census of Manufactures and 1950 Households Census for construction of new industrial-production indexes, for improved fuel-consumption data, and for checking national product data; (b) additional studies of changes in the use of heat and power per unit of product in individual industries and functions, and detailed study of probable future production costs of each of the energy commodities. Such revisions is currently underway.

We believe this study is a contribution in approach and method for government and private planning in the energy and minerals fields. Part of the approach, it may be noted, is a development, with modifications, from a statistical and conceptual apparatus conceived by Professor W. W. Leontief and described in his book, The Structure of the American Economy, 1919-1929 (Harvard University Press, 1941). Statistical compilations and analyses for other sectors of the economy, based on Professor Leontief's input-output scheme, are currently carried on by the Harvard Research Project and by the Bureau of Labor Statistics. Our energy study complements this boarder work.

APPENDIX

Chart and Table Explanations

A. "National product" is gross national product (GNP) in constant (1947) dollars. It is based on the published current dollar gross national product data of Department of Commerce and of Simon Kuznets, National Bureau of Economic Research. Although we are indebted to other government officials for advice in constructing deflators for the current dollar series and in filling in GNP data for the individual years for which no published data exist, they are not responsible for the unofficial GNP series used in the charts.

B. The B.t.u. series presented in chart A and the B.t.u. data that entered into the calculations for charts B, D, and E are from the Bureau of Mines "Annual Supply of Energy from Mineral Fuels and Water Power" (Mineral's Yearbook, 1947 and earlier years).

In all the other computations B.t.u. data are calculated from the conversion factors in table 19.

TABLE 19. - Conversion factors

Item	Unit	B.t.u. per unit
Bituminous coal	ton	26,200,000
Anthracite	ton	27,200,000
Crude oil	bbl.	6,000,000
Natural gas:		
Before treatment	cu. ft.	1,075
After treatment	cu. ft.	1,000
Natural gasoline	bbl.	4,620,000
Coke-oven and manufactured gas products:		
Coke	ton	26,000,000
Gas	cu. ft.	Converted to 540
Tar	bbl.	6,300,000
Light oils	bbl.	5,460,000
Refinery products:		
Motor fuel	bbl.	5,250,000
Kerosene	bbl.	5,640,000
Diesel and gas oil	bbl.	5,920,000
Residual fuel oil	bbl.	6,270,000
Coke	bbl.	6,000,000
Lubes	bbl.	6,060,000
Wax	bbl.	5,570,000
Asphalt	bbl.	6,640,000
Road oil	bbl.	6,640,000
Shale:		
Ore	ton	4,000,000
Oil	bbl.	6,000,000
Electric power and stationary direct drive:		
1939............................	kw.-hr.	18,340
1947............................	do.	17,065
1965............................	do.	11,377

C. The following definitions and assumptions have been used:

(a) Motion power, B.t.u.: Locomotive coal, fuel oil, Diesel oil, and gasoline; bunker coal, fuel oil, and Diesel oil; passenger-car gasoline; truck and bus gasoline; and gasoline used for all non-highway purposes (including tractors and other farm equipment, industrial and commercial use, construction, domestic use, marine use, and evaporation).

(b) Stationary power, kw.-hr.: All electric power generated, and all stationary direct-drive power except that itemized under motion power, above.

Stationary power, B.t.u.: Where power is shown as B.t.u. in order that it might be additive with other energy use, it is converted from kw.-hr. to fuel B.t.u. as indicated at the end of Section (B), above. Since efficiency in power production rises over time, the showing of fuel and hydro kw.-hr. in B.t.u. at the prevailing efficiencies understates the growth in power kw.-hr.

(c) Chemical materials, lubes, etc., B.t.u.: Comprised, roughly, of energy commodities that are not used as fuel: Lubes, wax, asphalt, and road oil from refineries; liquified petroleum gas (LPG), except natural gasoline, which is used as motor fuel; liquified refinery gas, except that used by refineries and manufactured-gas plants; tar, except that burned as fuel for heat or power in coke ovens, manufactured-gas plants, and iron and steel plants; and light oil derivatives from coke ovens and manufactured gas plants, except that portion of benzol used as motor fuel.

(d) Space and process heat, B.t.u.: Fuel consumed, except that for stationary or motion power, converted into "chemicals, lubes, etc," or exported. Includes energy industries' use as heat, and loss and waste; among these, for example, are waste of natural gas, and processing losses in refineries, coke ovens and manufactured-gas plants. (Does not include electric utility transmission and distribution losses or use; these losses are in stationary power.)

(e) Exports: gross exports of coal, oil, gas, coke, and refinery products.

(f) There are certain inconsistencies in summarizing the individual items for presentation in the four categories described. For example, trolley-car and electric locomotive electric power is "motion power" by function, but it was preferred to keep all electric power in one category, "stationary power." Similarly, electric furnace power appear in "stationary power," even though the function is "heat." Insofar as it is possible to determine, these arbitrary decisions do not impair the validity of conclusions drawn from the tables in the text. The groupings for presentation could not affect the 1965 projections, which were made from the individual items.

Projection of Underlying Variables

A. National Product

The projection of national product used in this paper puts the 1965 level at about 390 billions of 1947 dollars. This is 65 percent greater than the 1947 level of $232 billions. The implicit average annual compound rate of increase is about 3 percent. The proximate origin of the projection is a judgment by the Council of Economic Advisors that "A reasonable development for the next few years would be an annual increase in output of about 3 percent." (Economic Report of the President, Transmitted to Congress, January 1949, III. Basic Objectives for Balanced Economic Growth, p. 52.)

More basically, projections of national product increase of 2-1/2 or 3 percent under full employment peacetime conditions are the results of various government agency and private studies of changes in productivity per man-hour in various industries; growth in population; population age distribution; retirement age and work force entry age; and other variables. Charts C and F in this paper present series on deflated national product; page 51 of the report cited shows a slightly different and longer term series. As a rough check on reasonableness, it will be seen from the charts that a projection of national product growth at 3 percent per year is consistent with the historical record.

B. Output or Activity in Individual Non-Energy-Producing Sectors

In most of the cases, outputs of non-energy-producing sectors were projected as functions of national product and time. The functional relationship was estimated primarily from statistical analyses of changes in each sector's physical output (or output index) relative to past changes in deflated national product through time. Advice was sought on this relationship from economists specializing in particular industries. Further, consideration was given to which sectors of industry were likely to be the new product areas, and these considerations were related to the output estimates.

In a minority of the cases it was possible to project individual sectors on the basis of variables additional to national product. Studies of the Bonneville Power Administration were used to arrive at higher aluminum, magnesium, and electrothermal superphosphates output than could have been estimated from a national product relationship alone. In other electroprocess industries it was observed that substitutions of power for direct fuel processes or for other products were taking place, and these rates were added to the influence of increasing national product. In the case of mining output, other than fuels, consideration was given to the effect of diminishing reserves and the likelihood of increased imports.

In certain other cases even less direct weight was given to national product growth. The following are examples. The main variables used in estimating household requirements for heat were estimates of increase in numbers of families and estimates of new construction. Coal, oil, and gasoline exports were estimated at about the 1949 level, on considerations other than national product change. It was assumed that military use of fuel oil would remain unchanged from 1947. The five-fold increase in aviation fuel requirements is an industry estimate not based on national product change.

Changes in sector output were examined relative to national product changes in three other related sets of economy-wide projections, two of which were made some time ago for the year 1950. It was found that the assumption of unchanging inter-industry relations in these studies were inconsistent with the effects of wartime and post-war developments and so could not be used in these projections.

The final consideration was whether sector outputs were consistent with each other. By this is meant, for example, whether the forecast of output in the stone, clay, and glass industry is consistent with the volume of hydro construction; whether the volume of railroad traffic is consistent with the indicated coal output to be hauled; and whether electro-process steel output is consistent with total steel output.

This fundamental point is emphasized: Each of the projections, which are made primarily as functions of national product and time, is quite imperfect. Some of the sectors are almost as unhomogeneous as energy and some (e.g., chemicals) are more so. Like energy, these are too complex safely to project as aggregates. Further, the technological relationships of the components of many of the sectors to national product are, like individual energy supplies, changing because of technical advance and substitution, and one cannot know how significant these are from aggregates. What is needed is a detailed analysis of each sector's future, in which variables in addition to national product, time, population, and stocks are introduced.

Ultimately the Leontief BLS input-output table and procedure, now being revised on the basis of 1947 census data, will provide a far superior basis for estimating a consistent set of output projections for the non-energy-producing sectors. The present revision efforts now under way are designed to be merged with this larger apparatus and set of data.

C. Relationship Between Output Relatives and Income Elasticities

Static economic theory uses a concept which it calls the "income elasticity of demand." Income elasticity is defined as the percentage change in demand for a product relative to a percentage change in income. Thus, if Y symbolizes income, D demand for a product, and e the elasticity,

$$e = \frac{\Delta D}{D} \div \frac{\Delta Y}{Y}$$

If size of demand for a product is conceived to be identical with size of output of the industry sector producing that product, and if the size of income is conceived to be identical with the size of national production, then the above equation states also that elasticity measures the change in output of an industry relative to change in national product.

Conceive further that elasticities for a particular size income hold without respect to time or other variables; that is, that output of an industry sector depends solely on national product size. Then, given elasticities, national product, and sector outputs in 1947 and national product in 1965, relative output in 1965 is computed as follows:

$$e = \frac{D_{65} - D_{47}}{D_{47}} \div \frac{Y_{65} - Y_{47}}{Y_{47}}$$

$$\frac{D_{65} - D_{47}}{D_{47}} = e . \frac{Y_{65} - Y_{47}}{Y_{47}}$$

$$\frac{D_{65}}{D_{47}} = e . \frac{Y_{65} - Y_{47}}{Y_{47}} + 1$$

And $\frac{D_{65}}{D_{47}}$ is relative output.

As, however, the output relatives herein are at the minimum functions of time as well as national product; and as it is necessary to make the other assumptions indicated above to bridge the gap; the theorist cannot precisely relate his views on elasticities to these output relatives.

D. Unit Energy Requirements

Changes in unit energy requirements (coefficients) have had only slight and unsystematic previous analysis. The present studies are not exhaustive and do not give final conclusions. Coeficient changes result from substitutions of one energy for another, technical advances in combustion or other conversion of energy to useful work, and changes in other production techniques. These projections of 1965 coefficients are the results, primarily, of studies of past responses of sectors of the economy to these forces over time and of published and other opinion on technological changes already under way or on the immediate horizon. To the influence of relative price movements on future coefficients we have applied only intuitions, and these on too brief consideration, but prices are obviously important influences. A summary of our data appears later in this appendix.

Energy for Railroads

The textual explanation of the statistical apparatus described in the body of the paper may have been difficult to follow. The only purpose in presenting this case is to illustrate certain elements of the scheme. In order to highlight these elements, this illustration does not present arithmetic short-cuts that are actually employed in the study. Nor are the reasons presented for the judgments and assumptions used.

The Interstate Commerce Commission and the Association of American Railroads publish a number of series on railroad fuel purchases and consumption, some in physical units and some in B.t.u. equivalents. The B.t.u. equivalents data have been rejected because these are converted from physical units on widely differing bases by the individual reporting railroads.

The first problem is to arrive at the most complete figures possible for 1939 and 1947. It is necessary to make various adjustments and estimates in the individual items. For example, the ICC electricity data are electricity consumed, which means that both purchased and self-generated electric power are included. The purchased must be separated from self-generated (on the basis of FPC data on electricity purchased by railroads), for otherwise there would be counted in railway consumption both the fuel used for generation and the electric power generated. Similarly, certain ICC data include fuel of terminal and switching companies, whereas others exclude these; and the same is true of work-train service and of Class II and III railroads. (These adjustments are not large and are hardly worth making; but this was not apparent until after the work necessary to make the adjustments was done.)

It was decided to use data (table 20) in which "locomotives" are only those of Class I railroads, including terminal and switching companies, and "other" includes work-train service and nonlocomotive energy of Class I railroads and all energy used by Classes II and III railroads. This solution deliberately puts a trivial volume of locomotive fuel into "other" in preference to impairing the "locomotive" data of Class I railroads with Classes II and III, for which solid and detailed traffic and fuel data are not available. By setting "other" equal to fuel purchased less that charged to "locomotives," there is automatically included fuel stock changes in "other." Conceptually, this is improper, but practically it is permissible because the volumes involved are not significant.

There follows the breakdown in table 20 which includes double counting in that self-generated electricity and the fuels from which generated are both shown:

TABLE 20. - Energy for railroads, by products

	1939	1947
Locomotive		
Bituminous coal, t. tons	74,437	100,370
Anthracite, t. tons	719	42
Purchased electric power, m. kw.-hr.	1,564	2,194
Self-generated electric power, m. kw.-hr.	340	382
Gasoline, t. bbl.	550	302
Diesel oil, t. bbl.	867	17,536
Fuel oil, t. bbl.	55,500	89,783

TABLE 20. - Energy for railroads, by products (Cont'd.)

	1939	1947
Other		
Bituminous coal, t. tons	9,013	12,062
Anthracite, t. tons	963	899
Purchased electric power, m. kw.-hr.	283	423
Self-generated electric power, m. kw.-hr..	61	73
Gasoline, t. bbl.	551	841
Diesel oil, t. bbl.	294	1,526
Fuel oil, t. bbl.	5,574	6,972

The next steps are to translate these data into B.t.u. of energy supplies used and then to summarize them in terms of our functional classes, at the same time eliminating the double counting. The results appear in table 21.

TABLE 21. - Energy for railroads, by function

	1939	1947
Heat (10^{12} B.t.u.)	292	386
Stationary power (10^9 kw.-hr.)	0.3	0.5
Motion power:		
Coal-steam (10^{12} B.t.u.) .	1,970	2,631
Oil-steam (10^{12} B.t.u.) ..	348	563
Diesel (10^{12} B.t.u.)	5	103
Gasoline (10^{12} B.t.u.) ...	3	2
Electric (10^9 kw.-hr.	1.9	2.6

These are left for awhile to study locomotive performance. From ICC data on Class I railways, including switching and terminal companies but excluding work-train service; table 22 was compiled on the relative fuel performance of various types of locomotives:

TABLE 22. - Locomotive performance, by fuels

	1939	1947
Road freight service:	Per thousand gross ton miles	
Coal, lb.	115.00	123.00
Fuel oil, gal.	8.22	8.28
Diesel oil, gal.	-	1.60
Electric, kw.-hr.	28.73	28.85
Road passenger service:	Per passenger-train car-mile	
Coal, lb.	16.20	19.70
Fuel oil, gal.	1.07	1.05
Diesel oil, gal.	0.23	0.28
Electric, kw.-hr.	3.50	3.60
Yard switching:	Per locomotive-hour	
Coal, lb.	779.00	867.00
Fuel oil, gal.	59.16	61.43
Diesel oil, gal.	5.84	6.22
Electric, kw.-hr.	112.00	107.00
Gasoline, gal.	10.00	7.70

These data are next converted to B.t.u., and fuel B.t.u. performance of each type of locomotive in each service are expressed in each year as an index: coal-steam locomotive performance in each service in each year equals 100. The averagés at the foot of table 23 result from weighting each service in each year by the total of fuel consumed in that service in that year. (The weights used were the ICC "equated net tons - coal equivalent" figures. These are not the best possible weights, but they save time and they serve the immediate purpose satisfactorily.)

TABLE 23. - Locomotive performance indexes, by fuels

	1939	1947
Freight:		
Coal	100.0	100.0
Fuel oil	77.0	72.5
Diesel	-	14.0
Electric	6.6	6.6
Passenger:		
Coal	100.0	100.0
Fuel oil	71.1	57.4
Diesel	15.3	15.3
Electric	5.7	4.8
Switching:		
Coal	100.0	100.0
Fuel oil	81.8	76.3
Diesel	8.1	7.7
Electric	3.8	3.2
Gasoline	12.3	8.5
Weighted average:		
Coal	100.0	100.0
Fuel oil	76.4	70.0
Diesel	12.3	13.3
Electric	5.9	5.7
Gasoline	12.3	8.5

The assumption is made that Diesels operate at an average B.t.u. efficiency of 28 percent. On the basis of this assumption and of their relationships to Diesels, the empirical efficiencies of all locomotives are as indicated in table 24.

TABLE 24. - Locomotive efficiencies, by fuels

	B.t.u. efficiencies, percent	
	1939	1947
Coal	3.4	3.7
Fuel oil	4.5	5.3
Diesel	28.0	28.0
Electric	59.0	65.0
Gasoline	18.5	25.0

If these efficiency percentages are applied to the table that showed 1939 and 1947 consumption of fuel in motion function (the second table of this case study), the B.t.u. of work as compared with B.t.u. of energy used is obtained.

For cases C and D, it is now estimated that rail traffic by 1965 will not increase as much as national product, but rather will increase by 80 percent as much as national product. As national product increase is estimated at 65 percent of 1947, rail traffic is estimated at 52 percent over 1947. Within this framework, the following additional estimates and judgments are made: (a) re gasoline and electric locomotive activity or traffic, which are insignificant relative to total traffic, the former will stay unchanged and the latter will increase proportionately to the change in national product; (b) the rate of steam locomotive retirements and Diesel replacements will result in a 1965 situation in which three-fourths of steam and Diesel traffic will be moved by Diesels and one-fourth by coal-steam locomotives; (c) average Diesel efficiency will not increase by 1965, but average efficiency of coal-steam locomotives will, owing to retention of the best of existing steam equipment; (d) efficiency in heat production will increase; (e) more stationary power will be used per unit of rail "output." Table 25 applies these judgments.

TABLE 25. - Work table on energy for railroads, 1947 and 1965

	1947			1965				
	Energy used, B.t.u. or kw.-hr.	Efficiency, percent	Work, B.t.u. or kw.-hr.	Work relative to 1947, percent	Work, B.t.u. or kw.-hr.	Efficiency relative to 1947, percent	Efficiency, percent	Energy supplies required, B.t.u. or kw.-hr.
Heat, 10^{12} B.t.u.	393	70.0	275	152	420	111	78	539
Stationary power, 10^{9} kw.-hr. ...	0.5	100.0	0.4	228	1.1	100	100	1.1
Motion power:								
Coal, 10^{12} B.t.u.	2,630	3.7	97	-	1/59	150	5.6	1,055
Fuel oil, 10^{12} B.t.u.	563	5.3	30	0	0	-	-	0
Diesel, 10^{12} B.t.u.	104	28.0	29	-	2/179	100	28	638
Gasoline, 10^{12} B.t.u.	2	25.0	0.4	100	0.5	100	25	2
Total	3,299	-	157	152	238	-	-	1,694
Electric, 10^{9} kw.-hr.	2.6	65.0	1.7	165	2.8	100	65	4.2

Note: Figures have been rounded after computation.
1/ One-fourth of subtotal of 238, less gasoline of 0.5
2/ Three-fourths of subtotal of 238.

The first column shows energy used, by functions and, where relevant, by energy commodities. The next column shows estimated B.t.u. efficiency rates, most of which appear in the preceding table. The third column calculates work on the basis of these efficiencies. The fourth and fifth columns estimate increase in railroad work; the sixth and seventh, changes in B.t.u. efficiency in performing the increased work; and the seventh, the particular energy supplies required to perform the increased work at the indicated changed efficiencies.

Since the remaining steps lead away from the railway industry and into the energy industries, the numerical illustration is concluded at this point.

The remaining steps are:

(a) Translate heat into the specific fuels that will be used to provide it.

(b) Estimate the division of stationary power as (1) electric power, and (2) direct drive. (For railroads this cannot be done for lack of data on stationary prime movers, not driving generators; such data are available for manufacturing up to 1939.)

(c) Estimate the division of electric power as (1) purchased power and (2) self-generated.

(d) Translate self-generated power into purchased kw.-hr. and specific mineral fuels.

At this point supplies purchased are in terms of finished energy commodities.

(e) Aggregate, in separate groups, purchases from each of refineries, coal suppliers, electric utilities, etc.

(f) Translate electric utility power into fuel needed to produce it, taking account of electricity transmission and distribution losses.

(g) Translate refinery products into crude oil, natural gas, and other fuel intake into refineries, taking account of refinery losses. The same is done for purchased gas.

(h) Take account of fuel used or lost in crude oil and coal production.

(i) Take account of and translate back to sources electric energy purchased from utilities by refineries, natural gas, crude oil, and coal.

At the final point is left the volume of crude-oil output, natural-gas output, coal-mine output, and hydro output. The entire volume of this output is accounted for in sectors of use and functions to which applied.

Energy Inputs for Cases A, B, C, and D

Power, electric and stationary direct drive. - In all cases the hydroelectric power production is 300 billion kw.-hr. The remainder, about 510 billion kw.-hr. in cases A and B, is produced from mineral fuels as follows: bituminous coal, 60 percent ; natural gas, 20 percent; and oil, 20 percent. The remainder, about 505 billion kw.-hr. in cases C and D, is produced from mineral fuels in the following proportions: Bituminous coal, 78 percent; natural gas, 12 percent; and oil, 10 percent. These latter are approximately the proportions of thermal central station consumption of fuel in 1947.

Manufacturing and railroad nonmotive fuel for heat. - In case A, 20 percent of present work from solid fuels, except coke-oven products for the iron and steel industry, is displaced by oil and gas in the proportions 1/3 and 2/3, respectively. The increment of additional work in 1965, except coke-oven products for the iron and steel industry, is satisfied by mineral fuels in the following proportions: coal, 5 percent; oil, 35 percent; and gas, 60 percent.

Case B is the same as case A, except that the oil and natural-gas displacement and new work proportions are reversed.

In cases C and D there is no coal displacement, and the increment of new work, except for coke-oven products for the iron and steel industry, is satisfied by fuels in the same proportions as in 1947.

Household, commercial, and other heat. - Same as in manufacturing, above, except that the displacement of coal work in 1947 is 30 percent instead of 20 percent.

Energy-producing industries. - In all cases use their inputs and/or their own products.

Energy Coefficient Indexes

Energy coefficients are defined as energy input per unit of output of the consuming industry; that is, energy input divided by output of the consuming sector. These are ascertainable from published industry data; for example, census primary aluminum consumption of electric power in 1947 was 10 billion kw.-hr. and census primary aluminum output was about 560,000 tons, a coefficient of 10,405,000,000 ÷ 560,838, or about 18,500 kw.-hr. of electricity per ton of primary aluminum. Coefficients are also directly ascertainable from engineering data; for example, modern thermal central stations are designed for thermal efficiencies as high as 32 or 33 percent, i.e., about 3 B.t.u. of fuel input per B.t.u. of power output.

The following tables present some approximations of empirical coefficient indexes, which are calculated from Census and other industry data. In addition to these, other coefficients or coefficient indexes appear at other places in this paper.

A. Heat Coefficient Indexes

Numerators are calculated primarily from Census data. Denominators are Federal Reserve Board production indexes adjusted for coverage in some cases. Coefficient in 1939 = 100.

Industry group	1929	1939	1947
Food and kindred	108	100	86
Paper and allied	148	100	118
Stone, clay, and glass	153	100	84
Nonferrous metals	123	100	101
Iron and steel	121	100	103
Chemicals	-	100	78
Textiles and apparel	138	100	-

Numerators are calculated primarily from Census data. Denominators are indexes presented by Solomon Fabricant in "Employment in Manufacturing," 1899-1939 (National Bureau of Economic Research, 1942). Coefficient in 1939 = 100.

Industry groups	1929
Food and kindred group	112
Paper and allied group	145
Stone, clay, and glass group.	145
Nonferrous group	132
Iron and steel group	116
Chemicals group	60
Textiles and apparel group	138
Industries	
Cordage and twine	236
Collapsible tubes	131
Baking powder	110
Carpets, rugs (wool)	114
Lime	125
Caskets and coffins	122
Cast-iron pipe	127
Bread and other bakery products	91
Beet sugar	116
Concrete products	130

Numerators are calculated primarily from Census data, but fuel used for self-generated direct drive (i.e., non-electric) power has not been eliminated. Denominators are Federal Reserve Board production indexes, adjusted for coverage in some cases. Coefficient in 1939 = 100.

Industry groups	1947
Transportation equipment, exclusive of automobiles ..	203
Leather	110
Apparel	113
Textiles	85
Furniture	86
Tobacco manufactures	90
Machinery (except electrical)	65
Printing	75
Electrical machinery	73
Automobiles	35
Rubber	81

B. Power Coefficient Indexes

Numerators are kw.-hr. electric power plus direct-drive power consumed and are calculated primarily from Census data. Denominators are Federal Reserve Board indexes adjusted for coverage in some cases. Coefficient in 1939 = 100.

Industry group	1929	1939	1947
Food and kindred	90	100	100
Paper and allied	106	100	105
Stone, clay, and glass	98	100	91
Nonferrous metals	43	100	160
Iron and steel	72	100	97
Chemicals (new FR index)	-	100	103
Textiles and apparel	104	100	-

Numerators are kw.-hr. electric power plus direct-drive power consumed and are calculated primarily from Census data. Denominators are the Solomon Fabricant indexes cited earlier. Coefficient in 1939 = 100.

Industry group	1929
Food and kindred	93
Paper and allied	104
Stone, clay, and glass	92
Nonferrous metals	46
Iron and steel	69
Chemicals	114
Textiles and apparel	104

Industries	1929
Cordage and twine	75
Collapsible tubes	92
Baking powder	61
Carpets, rugs (wool)	65
Lime	76
Caskets and coffins	108
Cast-iron pipe	58
Bread and other bakery products	80
Beet sugar	93
Concrete products	79

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Numerators are kw.-hr. calculated from Census data, but self-generated direct drive (i.e., non-electric) power has not been included. Denominators are Federal Reserve Board production indexes. Coefficient in 1939 = 100.

Industry group	1947
Transportation equipment, excluding automobiles	165
Leather	129
Lumber	124
Apparel	165
Textiles	107
Rubber	106
Furniture	137
Tobacco	100
Machinery (except electrical)	106
Printing	110
Electrical machinery	98
Automobile	77
Food and kindred	107
Paper	115
Stone, clay, and glass	95
Nonferrous metals	163
Iron and steel	116
Chemicals (new FR index)	110

Numerators are horsepower of prime movers plus horsepower of electric motors driven by purchased electrical energy. Denominators are physical production volumes in most cases and production indexes in a few cases. Coefficient in 1929 = 100.

Industries	1919	1929	1939
All minerals industries	-	100	117
Bituminous coal	79	100	147
Anthracite	72	100	145
Iron ore	103	100	167
Copper	-	100	149
Lead	114	100	152
Limestone	-	100	195
Granite	-	100	370
Sand and gravel	-	100	180
Phosphate rock	92	100	106
Crude oil	-	100	181

Numerators are kw.-hr. of electric power consumed. Denominators are those indicated immediately above. Coefficient in 1929 = 100.

Industries	1939
Bituminous coal	137
Anthracite	145
Iron ore	113
Copper	113
Lead	106
Limestone	136
Granite	78
Sand and gravel	104
Phosphate rock	88

Numerators calculated from Census data, but self-generated direct drive (i.e., non-electric) power has not been included. Denominators are catch-as-catch-can calculations of output. Coefficient in 1939 = 100.

	1947
Collapsible tubes	152
Baking powder	166
Beet sugar	149

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TABLE 26. - Energy: Supplies (in 10^{12} B.t.u.)

Consumption function and sector	1939	1947	1965				
			All cases	Case A	Case B	Case C	Case D
Heat:							
Energy-producing industries:							
Bituminous coal	42	38		32	32	45	47
Anthracite	33	41		19	19	30	30
Crude oil	141	243		308	308	308	308
Natural gas, natural gasoline, and allied.	1,317	1,839		2,973	2,200	1,594	1,594
Coke ovens	199	540		726	726	731	731
Manufactured-gas utilities	89	119		96	96	118	118
Petroleum refineries	758	1,500		2,109	2,478	1,928	1,816
Synthetic oil	0	0		0	0	0	654
Total	2,579	4,320		6,263	5,859	4,754	5,298
Manufacturing (1939 Census groups), exclusive of refineries and coke ovens:							
Iron and steel	1,468	2,533	3,774				
Chemicals	660	1,152	2,383				
Textiles	190	221	302				
Stone, clay, and glass	494	750	1,117				
Food and kindred	415	515	674				
Paper and allied	232	375	559				
Nonferrous metals	123	204	305				
Other manufacturing, exclusive of refineries and coke ovens	390	744	1,153				
Total	3,972	6,494	10,267				
Railroad, nonmotive	299	393	540				
Commercial, household, and other:							
Identified as household	1,789	2,243		2,324	2,338	2,397	2,397
Household (unidentified), commercial, and other	4,110	5,939		8,521	8,592	8,855	8,855
Total	5,899	8,182		10,846	10,930	11,252	11,252
Total heat	12,749	19,389		27,916	27,596	26,813	27,357
Electric power and stationary direct drive:							
Energy-producing industries:							
Bituminous coal	58.9	96.9		99.2	99.1	139.8	145.0
Anthracite	31.7	35.6		28.4	28.4	45.7	45.7
Crude oil	42.6	65.8		101.0	101.0	101.0	101.0
Natural gas, natural gasoline, and allied.	54.6	128.9		211.9	166.7	113.4	113.4
Coke ovens	22.1	32.6		29.6	29.6	29.8	29.8
Manufactured-gas utilities	25.3	33.4		16.3	16.3	20.1	20.1
Petroleum refineries	83.8	135.4		167.5	196.8	153.1	144.2
Synthetic oil (both heat and power, B.t.u. presented under heat)	0	0		0	0	0	0
Electric utilities	497.8	682.3		1,258.2	1,255.2	1,248.8	1,248.0
Total	816.6	1,211.0		1,912.1	1,893.1	1,851.7	1,847.2
Electroprocess manufacturing (1939 Census groups), exclusive of refineries and coke ovens (S.I.C. and 1947 Census four-digit industries):							
Abrasive products-3291 (includes silicon carbide and aluminum oxide abrasives)	1.6	4.6	9.0				
Electrometallurgical products-3313 (primarily electroferroalloys)	47.0	83.7	207.8				
Primary nonferrous metals, nec-3339 (includes magnesium and cadmium)	.3	.5	2.3				
Alkalies and chlorine-2812	20.1	50.6	77.6				
Inorganic chemicals, nec-2819 (includes alumina, calcium carbide, and electric phosphorus	42.4	78.9	155.2				
Total, part of 1939 chemicals group	113.3	218.2	451.4				
Electrosteel, part of 3312	10.5	37.7	95.5				
Electric heat-treating (no number)	71.5	85.3	130.8				
Total, treated as part of 1939 iron and steel group	82.0	123.0	226.3				
Primary aluminum-3334	54.6	177.6	414.3				
Primary zinc-3333	10.5	22.8	37.0				
Primary copper-3331	21.4	12.6	12.3				
Aluminum rolling and drawing-3352	5.1	16.6	38.6				
Copper rolling and drawing-3351	8.3	16.8	25.8				
Total, part of 1939 nonferrous group.	99.8	246.4	528.0				
Carbon and graphite products-3612	5.5	8.9	21.4				
Total, electroprocess	298.7	596.6	1,227.2				
Manufacturing (1939 Census groups) exclusive of manufacturing items above:							
Iron and steel group	249.8	388.6	427.5				
Chemicals group	93.7	225.4	345.6				
Textiles group	128.9	174.5	176.9				
Stone, clay, and glass group	97.4	149.4	164.4				
Food and kindred group	137.1	185.4	216.6				
Paper group	200.3	278.5	306.4				
Nonferrous group	12.8	30.8	33.8				
Other manufacturing groups	249.1	466.8	802.9				
Total	1,168.2	1,899.4	2,474.0				
Total, manufacturing exclusive of petroleum refineries and coke ovens	1,466.9	2,496.0	3,701.2				

TABLE 26. - Energy: Supplies (in 10^{12} B.t.u.) (Cont'd.)

Consumption function and sector	1939	1947	1965				
			All cases	Case A	Case B	Case C	Case D
Electric power and stationary direct drive: (Cont.d)							
Railroads:							
Locomotives	28.7	37.4	41.2				
Nonmotive	5.2	7.2	11.0				
Total	33.9	44.7	52.2				
Household, commercial, and other:							
Household	421.2	848.8	1,782.6				
Street and interurban railways	71.9	76.6	67.6				
Public authorities; street and highway lighting	86.5	150.6	248.5				
Commercial	386.8	737.2	1,287.7				
Other	114.8	161.5	172.5				
Total	1,081.2	1,974.7	3,559.0				
Total, electric power and stationary direct drive	3,398.6	5,726.3		9,224.5	9,205.5	9,164.1	9,159.6
Motion power:							
Railroad locomotives:							
Coal	1,969.8	2,630.8		832.1	832.1	1,055.4	1,055.4
Fuel oil	348.0	563.0		0	0	0	0
Diesel oil	5.1	103.8		637.5	637.5	637.5	637.5
Gasoline	2.9	1.6		1.4	1.4	1.4	1.4
Electric power (included in Electric power and stationary direct drive, above)							
Total, railroad motive	2,325.8	3,299.2		1,471.0	1,471.0	1,694.3	1,694.3
Bunker:							
Coal	72.4	78.3	66.7				
Fuel oil	408.5	644.1	644.1				
Diesel oil	83.5	80.5	223.7				
Total, bunker	564.4	802.9	934.5				
Motor fuel:							
Cars	1,877.6	2,512.1	2,994.4				
Other highway	711.7	1,014.9	1,396.5				
Aviation	22.0	113.4	600.0				
Other nonhighway	270.5	528.8	698.0				
Total, motor fuel	2,881.8	4,169.2	5,688.9				
Tractor fuel - kerosine and Diesel only	53.9	70.7	181.3				
Army, Navy, Coast Guard - Diesel and fuel oil only	77.8	150.7	150.7				
Total, motion power	5,903.7	8,492.6		8,426.4	8,426.4	8,648.7	8,649.7
Exports:							
Bituminous coal	303.7	1,801.4	729.5				
Anthracite	70.4	231.5	134.5				
Crude oil	432.5	278.1	0				
Natural gas	3.1	17.7	0				
Coke-oven coke	15.3	21.7	14.3				
Refinery products:							
Motor fuel	234.4	249.6	207.7				
Kerosine	46.5	41.0	14.3				
Diesel and other gas oil	189.6	177.2	72.3				
Residual fuel oil	109.6	67.4	80.2				
Coke	8.9	12.6	14.9				
Miscellaneous	.7	13.1	9.0				
Lubes	80.0	86.3	78.7				
Wax	4.6	6.2	5.8				
Asphalt	1.5	21.4	10.2				
Total exports	1,500.8	3,025.1	1,371.5				
Domestic chemical materials, lubes, etc.:							
Coke ovens: Tar and oil	30.8	69.7		115.0	115.0	115.0	115.0
Manufactured-gas utilities: Tar and oil	24.0	33.6		28.0	28.0	33.0	33.0
Refinery products: Lubes, wax, asphalt, road oil, miscellaneous	423.5	866.1		1,457.0	1,457.0	1,452.0	1,452.0
Total, chemical materials, etc.	478.3	969.4		1,600.0	1,600.0	1,600.0	1,600.0
Recapitulation:							
Heat	12,749	19,389		27,916	27,596	26,813	27,357
Electric power and stationary direct drive	3,399	5,726		9,225	9,206	9,164	9,160
Motion	5,904	8,493		8,426	8,426	8,650	8,650
Exports	1,501	3,025		1,372	1,372	1,372	1,372
Domestic chemical materials, lubes, etc.	478	969		1,600	1,600	1,600	1,600
Total, consumption and loss	24,031	37,602		48,539	48,200	47,599	48,139
Check totals: Energy production and imports	24,020	37,710		48,538	48,199	47,597	48,136

Note: Totals will not add owing to rounding.

TABLE 27. - Energy: Work (in 10^{12} B.t.u.)1/

Consumption function and sector	1939	1947	1965				
			All cases	Case A	Case B	Case C	Case D
Heat:							
Energy-producing industries:							
Bituminous coal	27	27		25	25	35	37
Anthracite	21	29		15	15	23	23
Crude oil	89	170		240	240	240	240
Natural gas, natural gasoline, and allied	829	1,287		2,313	1,711	1,240	1,240
Coke ovens	125	378		565	565	569	569
Manufactured-gas utilities	56	83		75	75	92	92
Petroleum refineries	477	1,050		1,640	1,927	1,500	1,412
Synthetic oil	0	0		0	0	0	509
Total	1,624	3,024		4,873	4,558	3,699	4,122
Manufacturing (1939 Census groups), exclusive of refineries and coke ovens:							
Iron and steel	925	1,773	2,944				
Chemicals	416	806	1,859				
Textiles	120	154	236				
Stone, clay, and glass	311	525	872				
Food and kindred	261	360	526				
Paper and allied	146	263	436				
Nonferrous metals	78	143	238				
Other manufacturing, exclusive of refineries and coke ovens	245	521	899				
Total	2,502	4,545	8,010				
Railroad, nonmotive	188	275	420				
Commercial, household, and other:							
Identified as household	974	1,351	1,621				
Household (unidentified), commercial, and other	2,354	3,628	5,826				
Total	3,328	4,979	7,447				
Total heat	7,642	12,823		20,750	20,435	19,576	19,999
Electric power and stationary direct drive:							
Energy-producing industries:							
Bituminous coal	11.0	19.4		29.7	29.7	41.9	43.5
Anthracite	5.9	7.1		8.5	8.5	13.7	13.7
Crude oil	7.9	13.2		30.3	30.3	30.3	30.3
Natural gas, natural gasoline, and allied	10.2	25.8		63.6	50.1	34.0	34.0
Coke ovens	4.1	6.5		8.9	8.9	8.9	8.9
Manufactured-gas utilities	4.7	6.7		4.9	4.9	6.0	6.0
Petroleum refineries	15.6	27.1		50.3	59.0	45.9	43.3
Synthetic oil (both heat and power B.t.u. presented under heat)	0	0		0	0	0	0
Electric utilities	92.6	136.5		377.4	376.6	374.6	374.4
Total	152.0	242.3		573.6	568.0	555.3	554.1
Electroprocess manufacturing (1939 Census groups), exclusive of refineries and coke ovens (S.I.C. and 1947 Census four-digit industries):							
Abrasive products-3291 (includes silicon carbide and aluminum oxide abrasives)	.3	.9	2.7				
Electrometallurgical products-3313 (primarily electroferroalloys)	8.7	16.7	62.2				
Primary nonferrous metals, nec-3339 (includes magnesium and cadmium)	.1	.1	.7				
Alkalies and chlorine-2812	3.7	10.1	23.3				
Inorganic chemicals, nec-2819 (includes alumina, calcium carbide, and electric phosphorus	7.9	15.8	46.5				
Total, part of 1939 Census chemicals group	20.7	43.6	135.4				
Electrosteel, part of 3312	2.0	7.5	28.6				
Electric heat-treating (no number)	13.3	17.1	39.3				
Total, treated as part of 1939 iron and steel group	15.3	24.6	67.9				
Primary aluminum-3334	10.2	35.5	124.3				
Primary mine-3333	2.0	4.6	11.1				
Primary copper-3331	4.0	2.5	3.7				
Aluminum rolling and drawing-3352	.9	3.3	11.6				
Copper rolling and drawing-3351	1.5	3.4	7.7				
Total, part of 1939 nonferrous group	18.6	49.3	158.4				
Carbon and graphite products-3612	1.0	1.8	6.4				
Total, electroprocess	55.6	119.3	368.1				
Manufacturing (1939 Census groups) exclusive of manufacturing items above:							
Iron and steel group	46.3	77.7	128.2				
Chemicals group	17.4	45.1	103.7				
Textiles group	24.0	34.9	53.1				
Stone, clay, and glass group	18.1	29.9	49.3				
Food and kindred group	25.5	37.1	65.0				
Paper group	37.3	55.7	91.9				
Nonferrous group	2.4	6.1	10.1				
Other manufacturing groups	46.4	93.4	240.9				
Total	217.4	379.9	742.2				
Total, manufacturing exclusive of petroleum refineries and coke ovens	273.0	499.2	1,110.3				
Railroads:							
Locomotives	5.3	7.5	12.4				
Nonmotive	1.0	1.4	3.3				
Total	6.3	8.9	15.7				
Household, commercial, and other:							
Household	78.3	169.8	534.8				
Street and interurban railways	13.4	15.3	20.3				
Public authorities; street and highway lighting	16.1	30.1	74.6				
Commercial	72.0	147.4	386.3				
Other	21.4	32.3	51.7				
Total	201.2	394.9	1,067.7				
Total, electric power and stationary direct drive	632.5	1,145.3		2,767.2	2,761.6	2,748.9	2,747.7

TABLE 27. - Energy: Work (in 10^{12} B.t.u.)1/ (Cont'd.)

Consumption function and sector	1939	1947	1965				
			All cases	Case A	Case B	Case C	Case D
Motor power:							
Railroad locomotives:							
Coal	67.0	97.3		46.6	46.6	59.1	59.1
Fuel oil	15.7	29.8		0	0	0	0
Diesel oil	1.4	29.1	178.5				
Gasoline	.5	.4	.4				
Electric power (included in Electric power and stationary direct drive, above)							
Total, railroad motion	84.6	156.6		225.5	225.5	238.0	238.0
Bunker:							
Coal	4.3	4.7	4.0				
Fuel oil	36.8	58.0	58.0				
Diesel oil	15.0	14.5	40.3				
Total, bunker	56.1	77.2	102.3				
Motor fuel:							
Cars	319.2	452.2	673.7				
Other highway	121.0	182.7	314.2				
Aviation	3.7	20.4	135.0				
Other nonhighway	46.0	95.2	157.1				
Total, motor fuel	489.9	750.5	1,280.0				
Tractor fuel - kerosine and Diesel only	9.5	12.7	37.6				
Army, Navy, Coast Guard - Diesel and fuel oil only	8.3	16.9	16.9				
Total, motion power	648.4	1,013.9		1,662.3	1,662.3	1,674.8	1,674.8
Exports:							
Bituminous coal	151.9	900.7	364.8				
Anthracite	35.2	115.8	67.3				
Crude oil	216.2	139.0	0				
Natural gas	1.6	8.8	0				
Coke-oven coke	7.6	10.8	7.2				
Refinery products:							
Motor fuel	117.2	124.8	103.9				
Kerosine	23.2	20.5	7.2				
Diesel and other gas oil	94.8	88.6	36.2				
Residual fuel oil	54.8	33.7	40.1				
Coke	4.4	6.3	7.5				
Miscellaneous	.4	6.6	4.5				
Lubes	40.0	43 2	39.4				
Wax	2.3	3.1	2.9				
Asphalt	.8	10.7	5.1				
Total exports	750.4	1,512.6	686.1				
Domestic chemical materials, lubes, etc.:							
Coke ovens: Tar and oil	15.4	34.9		57.5	57.5	57.5	57.5
Manufactured-gas utilities: Tar and oil	12.0	16.8		14.0	14.0	16.5	16.5
Refinery products: Lubes, wax, asphalt, road oil, miscellaneous	211.8	433.1		728.5	728.5	726.0	726.0
Total, chemical materials, etc.	239.2	484.8		800.0	800.0	800.0	800.0
Recapitulation:							
Heat	7,642	12,823		20,750	20,435	19,576	19,999
Electric power and stationary direct drive	633	1,145		2,767	2,762	2,749	2,748
Motion	648	1,014		1,662	1,662	1,675	1,675
Exports	750	1,513		686	686	686	686
Domestic chemical materials, lubes, etc.	239	485		800	800	800	800
Total, consumption and loss	9,912	16,980		26,665	26,345	25,486	25,908

Note: Totals will not add owing to rounding.

1/ To compile this table of "work", the purpose of which was to produce totals, the following efficiencies (B.t.u. ÷ B.t.u. energy supply input) were applied to energy supply inputs:

	Percent		
	1939	1947	1965
Heat for industry	63.00	70.00	77.78
Heat for household, commercial, and other:			
Anthracite	45.00	50.00	60.00
Bituminous coal	55.00	60.00	65.00
Coke	60.00	60.00	65.00
Gas	70.00	70.00	75.00
Fuel oil	65.00	65.00	70.00
Kerosine	60.00	60.00	-
All power	18.61	20.00	30.00
Locomotive fuel (other than electric power):			
Bituminous coal	3.40	3.70	5.60
Fuel oil	4.50	5.30	-
Diesel oil	28.00	28.00	28.00
Motor fuel	18.50	25.00	25.00
Motor fuel and kerosine tractor fuel	17.00	18.00	22.50
Bunker fuel:			
Coal	6.00	6.00	6.00
Diesel oil	18.00	18.00	18.00
Other oil	9.00	9.00	9.00
Army, Navy, and Coast Guard:			
Diesel oil	18.00	18.00	18.00
Other oil	10.00	10.00	10.00
Exports	50.00	50.00	50.00
Chemical materials, lubes, etc.	50.00	50.00	50.00

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TABLE 28. - 1965 Indexes

Consumption function and sector	Output or activity, all cases	Work per unit of output (1947 = 100)	Energy supply input ÷ work	Energy supply required, all cases
Heat:				
Energy-producing industries:				
Bituminous coal	a/	b/	b/	a/
Anthracite	a/	b/	b/	a/
Crude oil	a/	b/	b/	a/
Natural gas, natural gasoline, and allied	a/	b/	b/	a/
Coke ovens	a/	b/	b/	a/
Manufactured-gas utilities	a/	b/	b/	a/
Petroleum refineries	a/	b/	b/	a/
Synthetic oil	a/	b/	b/	a/
Manufacturing (1939 Census groups), exclusive of refineries and coke ovens:				
Iron and steel	165	100	90	149
Chemicals	230	100	90	207
Textiles	152	100	90	137
Stone, clay, and glass	165	100	90	149
Food and kindred	146	100	90	131
Paper and allied	165	100	90	149
Nonferrous metals	165	100	90	149
Other manufacturing, exclusive of refineries and coke ovens	172	100	90	155
Railroad: Nonmotive	152	100	90	137
Commercial, household, and other:				
Identified as household	120	c/	c/	-
Household (unidentified), commercial and other	165	c/	c/	-
Electric power and stationary direct drive:				
Energy-producing industries:				
Bituminous coal	a/	d/	67	a/
Anthracite	a/	d/	67	a/
Crude oil	a/	d/	67	a/
Natural gas, natural gasoline, and allied	a/	d/	67	a/
Coke ovens	a/	d/	67	a/
Manufactured-gas utilities	a/	d/	67	a/
Petroleum refineries	a/	d/	67	a/
Synthetic oil (both heat and power B.t.u. presented under heat)	a/	d/	67	a/
Electric utilities	a/	e/	67	a/
Electroprocess manufacturing (1939 Census groups), exclusive of refineries and coke ovens (S.I.C. and 1947 Census four-digit industries):				
Abrasive products-3291 (includes silicon carbide and aluminum oxide abrasives)	295	100	67	196
Electrometallurgical products-3313 (primarily electroferroalloys)	372	100	67	248
Primary nonferrous metals, nec-3339 (includes magnesium and cadmium)	620	100	67	413
Alkalies and chlorine-2812	230	100	67	153
Inorganic chemicals, nec-2819 (includes alumina, calcium carbide, and electric phosphorus)	295	100	67	197
Electrosteel - part of 3312	380	100	67	253
Electric heat-treating - no number	230	100	67	153
Primary aluminum-3334	350	100	67	233
Primary zinc-3333	343	100	67	162
Primary copper-3331	146	100	67	97
Aluminum rolling and drawing-3352	350	100	67	233
Copper rolling and drawing-3351	230	100	67	153
Carbon and graphite products-3612	360	100	67	240
Manufacturing (1939 Census groups), exclusive of manufacturing items above):				
Iron and steel group	165	100	67	110
Chemicals group	230	100	67	153
Textiles group	152	100	67	101
Stone, clay, and glass group	165	100	67	110
Food and kindred group	146	120	67	117
Paper group	165	100	67	110
Nonferrous group	165	100	67	110
Other manufacturing groups	172	150	67	172
Railroads:				
Locomotives	165	100	67	110
Nonmotive	152	150	67	152
Household, commercial, and other:				
Household	f/	f/	67	210
Street and interurban railways	133	100	67	85
Public authorities; street and highway lighting	165	150	67	165
Commercial	g/	g/	67	175
Other	h/	h/	67	107

TABLE 28. - 1965 Indexes (Cont'd.)

Consumption function and sector	Output or activity, all cases	Work per unit of output (1947 = 100)	Energy supply input ÷ work	Energy supply required, all cases
Motion power:				
Railroad locomotives:				
Coal	i/48	100	67	j/32
Fuel oil	0	-	-	0
Diesel oil	613	100	100	613
Gasoline	100	100	100	100
Electric power (included in Electric power and stationary direct drive, above)				
Total, railroad motion	k/144	100	-	l/45
Bunker:				
Coal	85	100	100	85
Fuel oil	100	100	100	100
Diesel oil	278	100	100	278
Total, bunker	133	100	-	116
Motor fuel:				
Cars	149	100	80	119
Other highway	172	100	80	138
Aviation	h/	h/	h/	529
Other nonhighway	165	100	80	132
Tractor fuel: Kerosine and Diesel only	295	100	-	256
Army, Navy, Coast Guard: Diesel and fuel oil only	100	100	100	100

Note: Products will not check, owing to rounding.

a/ These outputs and requirements were not estimated directly (see text).

b/ Energy supply required for heat per B.t.u. of net output for each producing sector was estimated as follows:

B.t.u. consumption and loss per B.t.u. of net output

	1939, B.t.u.	1947, B.t.u.	1965 relative to 1947, percent	1965, B.t.u.
Bituminous coal	0.00413	0.00231	100	0.00231
Anthracite	.02438	.01923	100	.01923
Crude oil	.01833	.02099	100	.02099
Natural gasoline and allied	2.86951	1.75380	50	.87690
Natural gas	.22973	.14587	100	.14587
Coke ovens	.14695	.24921	100	.24921
Manufactured gas	.30937	.31950	100	.31950
Petroleum refining	.10878	.14103	100	.14103
Synthetic oil	-	.81818	100	.81818

Note: The synthetic oil figure includes B.t.u. for power.

c/ The following estimated average efficiencies (energy supply input ÷ work) were used for household, commercial, and other:

	Percent	
	1947	1965
Anthracite	50	60
Bituminous coal and coke	60	65
Kerosine	60	-
Fuel oil	65	70
Gas	70	75

d/ Power supply required per B.t.u. of net output for each producing sector was estimated as follows:

Kw.-hr. consumption per million B.t.u. of net output

	1939, kw.-hr.	1965, relative to 1939, percent	1965, kw.-hr.
Bituminous coal	0.3133	200	0.6266
Anthracite	1.2732	200	2.5464
Crude oil	.3021	200	.6042
Natural gasoline	7.6103	100	7.6103
Natural gas	.4223	150	.63345
Coke ovens	.8931	100	.8931
Manufactured gas	4.7730	100	4.7730
Petroleum refineries	.6563	150	.98445
Synthetic oil (included in heat requirement)	-	-	-

e/ Power supply required per kw.-hr. of net output for 1965 was estimated at 0.18425. This is the same as the 1947 ratio and lower than the 1939 ratio of about 0.26.

f/ Estimated on the basis of numbers of residential customers and average use per residential customer.

g/ Department of Commerce estimate.

h/ Not estimated directly.

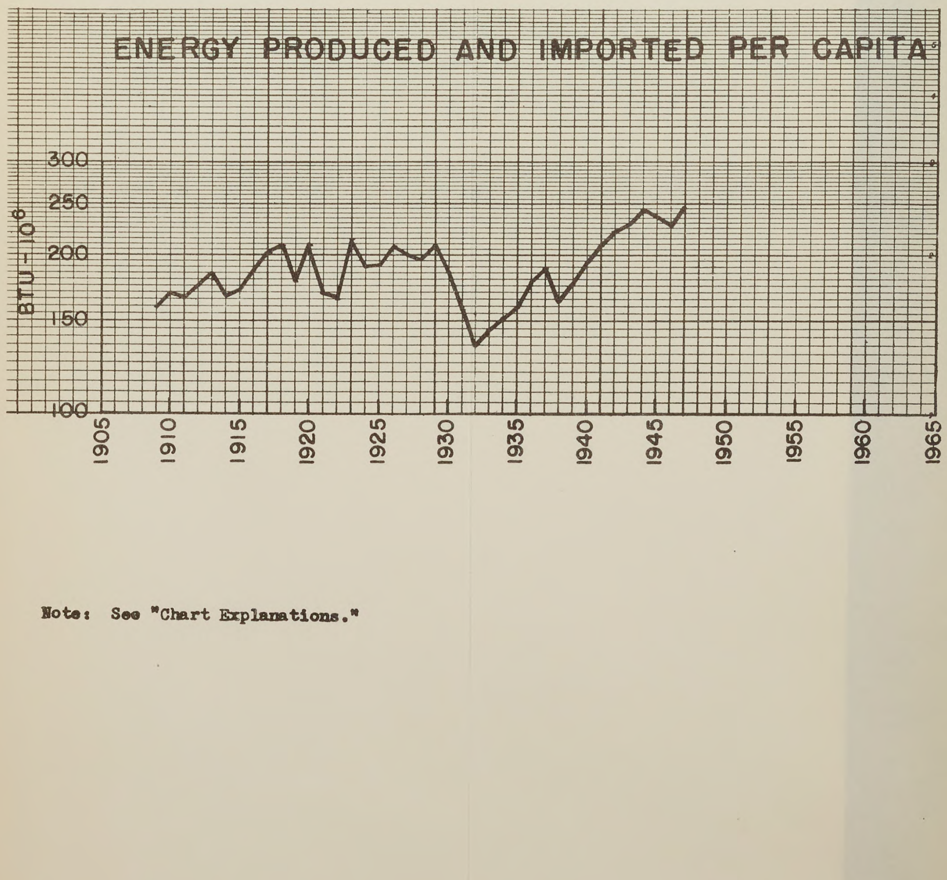
i/ Cases A and B only. The figure for cases C and D is 61.

j/ Cases A and B only. The figure for cases C and D is 40.

k/ Cases A and B only. The figure for cases C and D is 152.

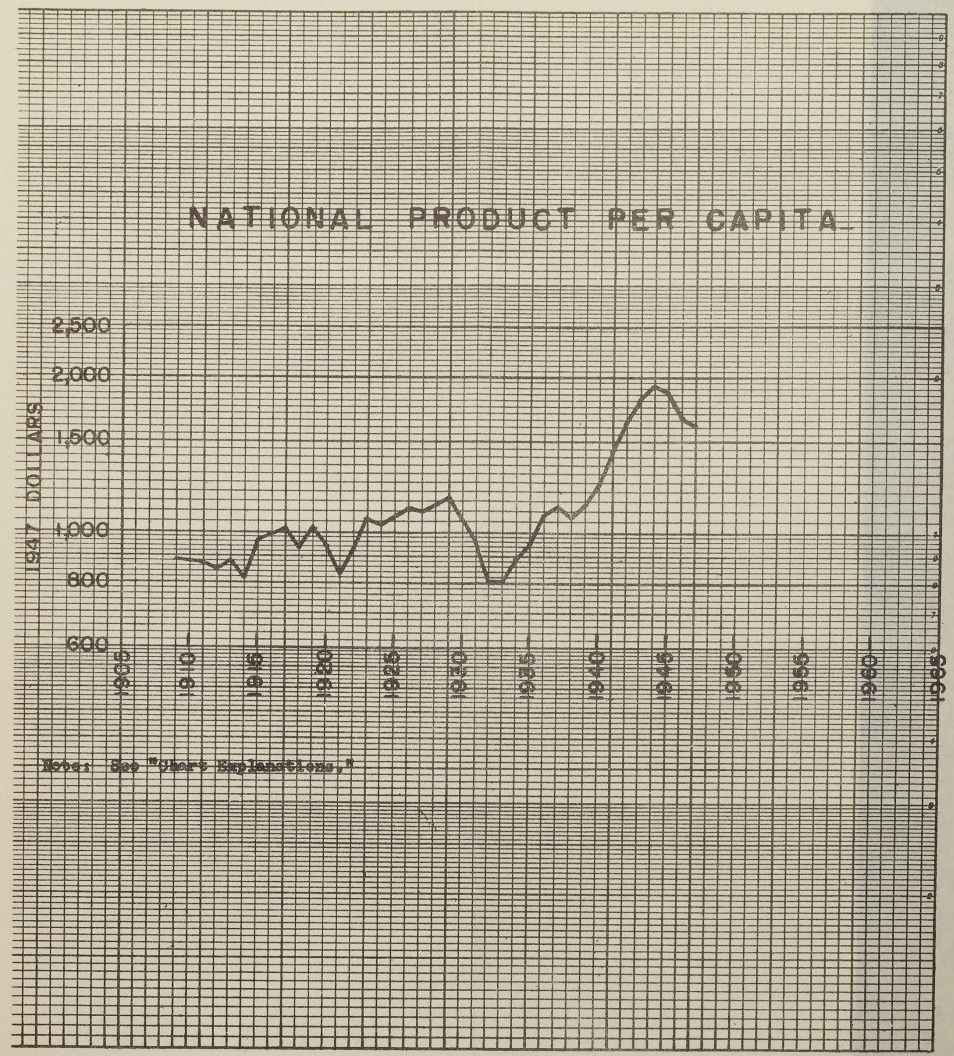
l/ Cases A and B only. The figure for cases C and D is 51.

Chart B



Note: See "Chart Explanations."

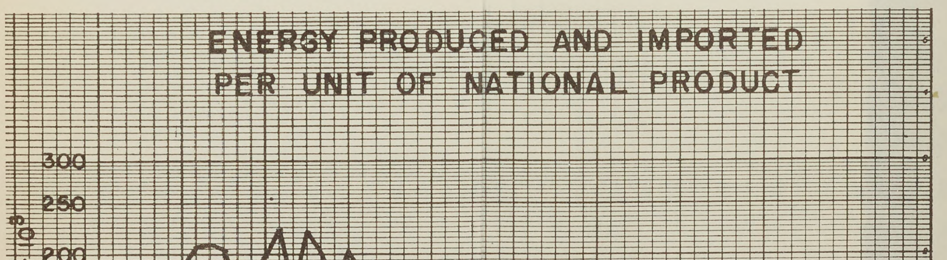
Chart C



NATIONAL PRODUCT PER CAPITA

Note: See "Chart Explanations."

Chart D



Note: See "Chart Explanations."

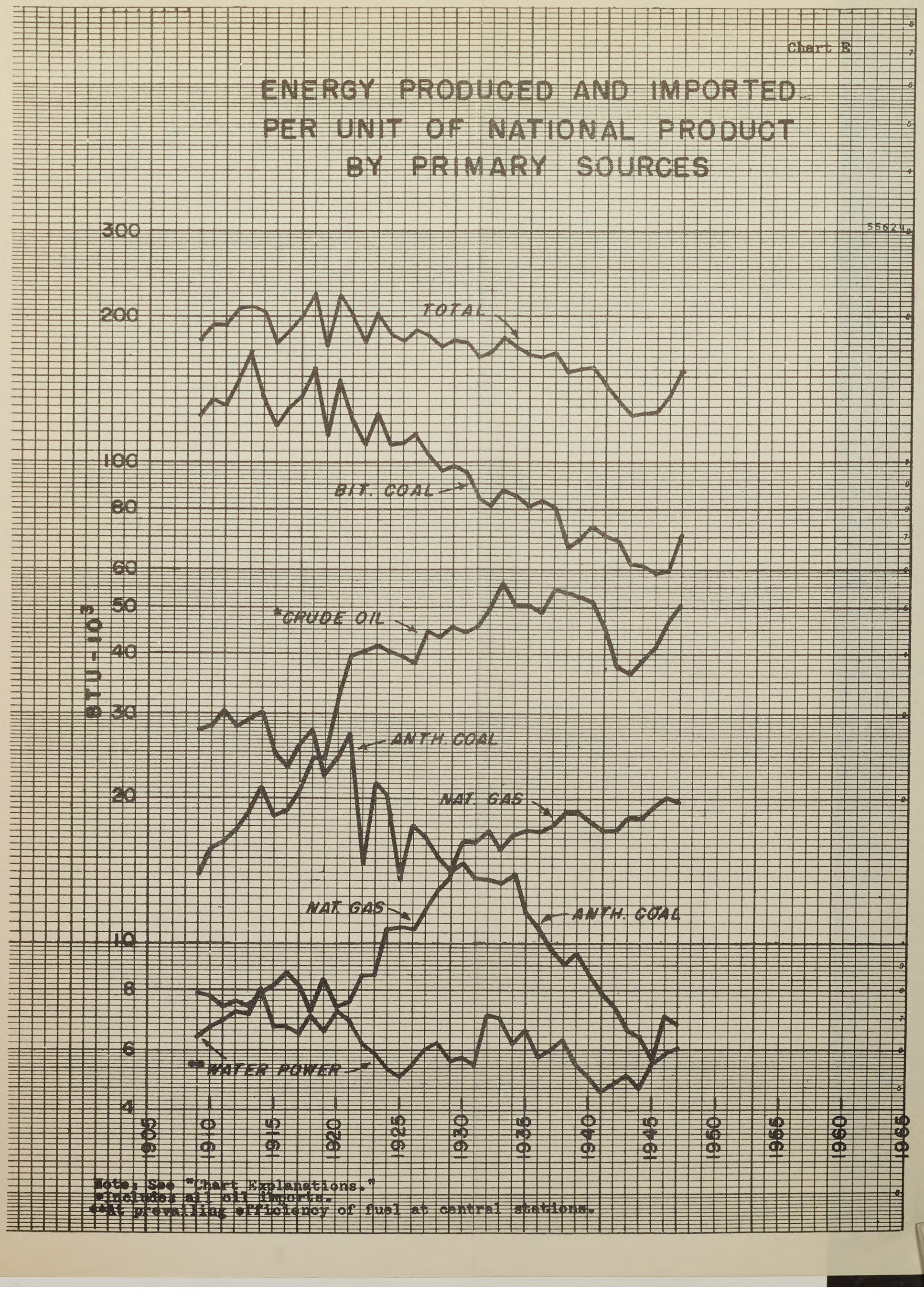
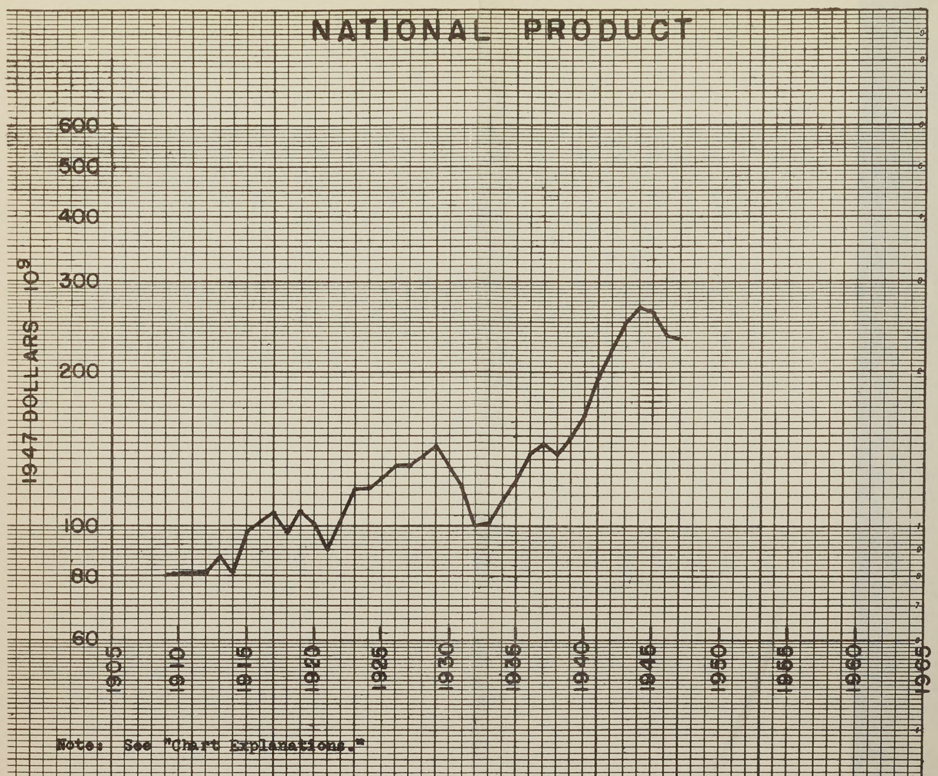


Chart E

ENERGY PRODUCED AND IMPORTED PER UNIT OF NATIONAL PRODUCT BY PRIMARY SOURCES

Note: See "Chart Explanations."
*Includes all oil imports.
**At prevailing efficiency of fuel at central stations.

Chart F



NATIONAL PRODUCT

Note: See "Chart Explanations."